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FINAL REPORT

ON

AN EXPLORATORY INVESTIGATION OF THE INFLUENCE OF IGNITER CHEMISTRY ON IGNITION IN POROUS BED GUN PROPELLANTS

Contract No. N00174-80-C-0138
Mod P00002

Performance Period

May 1981 - September 1981

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Gun Systems Engineering
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Submitted by

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In order to quantitize the ignition effectiveness of an igniter material, it is desirable to establish both the total energy deposition and the rate of energy deposition required to produce a sustained ignition in a live propellant bed. The primary objective of the current project was to use the igniter system developed under the initial phase of the Contract ~~N00174-80-C-0138~~ and conduct a series of diagnostic experiments to

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20. investigate the ignitibility of NACO propellants when subjected to different ignition stimuli (e.g., not gases, liquids, solids) as represented by BP, $BKNO_3$, and NC igniter materials. A secondary objective was to calibrate the igniter system with IMR 4895.

During the current contract, Applied Combustion Technology, Inc. has conducted 61 tests, including:

1. Igniter calibration with IMR 4895 to document baseline NC igniter performance.

2. Primer penetration tests with live NACO to insure that the primer input into the propellant bed would not lead to NACO ignition in the absence of igniter material.

3. Igniter penetration tests with inert simulant and NACO propellant to determine the igniter effectiveness for a fixed energy content as a function of zone thickness for an inert simulant positioned between the igniter vent and the NACO propellant. and

4. Igniter effectiveness tests with inert simulant and NACO propellant to determine the igniter effectiveness as a function of igniter energy level for a fixed zone thickness of inert simulant positioned between the igniter vent and the NACO propellant.

Igniter penetration tests and igniter effectiveness were conducted with BP, $BKNO_3$ (granular), and IMR 4895 (NC) and indicated that $BKNO_3$ was a more effective igniter material with NACO than either BP or NC. Test data and analyses to support this conclusion are presented.

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PREFACE

This report summarizes project analyses and results for the experimental documentation of the ignition effectiveness of NACO propellant with black powder, boron potassium nitrate, and nitrocellulose igniter materials using the Ignition Energetics Characterization Device (IECD). The results presented herein represent Phase II experimental results; Phase I of Contract N00174-80-C-0138 focused upon the development of an igniter system for the current experiments. The experimental program was conducted under Contract N00174-80-C-0138, Mod P00002 by Applied Combustion Technology, Inc., Orlando, Florida from May 1981 to September 1981. Mr. Charles Irish served as program manager for NOSIH. Applied Combustion Technology, Inc.'s program manager was Dr. A. Michael Varney.

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1.0 INTRODUCTION

1.1 Background

Applied Combustion Technology, Inc. has been involved in research to further understand the ignition effectiveness of various igniter materials with NACO propellant. As part of this ongoing research, Applied Combustion Technology, Inc. has designed, fabricated, and developed an ignition energetics characterization device (IECD) capable of conducting controlled ignition experiments under simulated gun conditions. The results presented herein document the ignition effectiveness of black powder (BP), boron potassium nitrate ($BKNO_3$), and IMR 4895 (NC) with NACO propellant.

1.2 Project Objectives

In order to quantitize the ignition effectiveness of an igniter material, it is desirable to establish both the total energy deposition and the rate of energy deposition required to produce a sustained ignition in a live propellant bed. The primary objective of the current project was to use the igniter system developed under the initial phase of Contract N00174-80-C-0138 and conduct a series of diagnostic experiments to investigate the ignitibility of NACO propellants when subjected to different ignition stimuli (e.g., hot gases, liquids, solids) as represented by BP, $BKNO_3$, and NC igniter materials. A secondary objective was to calibrate the igniter system with IMR 4895.

1.3 Achievements

During the current contract, Applied Combustion Technology, Inc. has conducted 61 tests, including:

1. Igniter calibration with IMR 4895 to document baseline NC igniter performance.
2. Primer penetration tests with live NACO to insure that the primer input into the propellant bed would not lead to NACO ignition in the absence of igniter material.

3. Igniter penetration tests with inert simulant and NACO propellant to determine the igniter effectiveness for a fixed energy content as a function of zone thickness for an inert simulant positioned between the igniter vent and the NACO propellant.
4. Igniter effectiveness tests with inert simulant and NACO propellant to determine the igniter effectiveness as a function of igniter energy level for a fixed zone thickness of inert simulant positioned between the igniter vent and the NACO propellant.

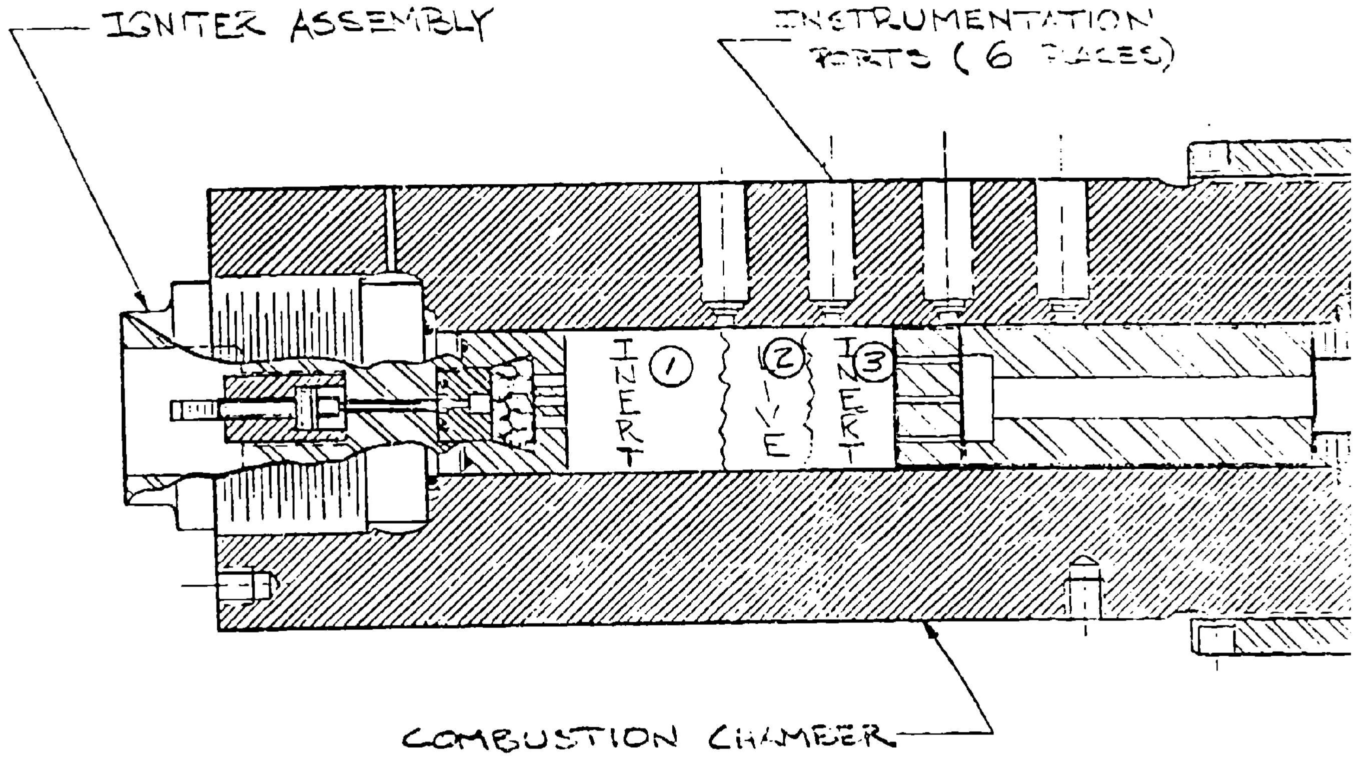
Igniter penetration tests and igniter effectiveness were conducted with BP, $BKNO_3$ (granular), and IMR 4895 (NC) and indicated that $BKNO_3$ was a more effective igniter material with NACO than either BP or NC. Test data and analyses to support this conclusion are presented in the following sections.

2.0 EXPERIMENTAL RESULTS

2.1 IECD Hardware Description

The IECD hardware, Figure 2.1, consists of five functional elements, listed below, and ancillary apparatus described in Appendix C:

1. Igniter Assembly. The igniter assembly consists of an end closure cap machined to accept an electrically initiated primer and a variety of different igniter configurations, including axial vent (shown), radial vent, and bayonet type systems.
2. Combustion Chamber. The combustion chamber is made from aircraft grade E-4340 steel, hardened to a minimum yield strength of 200 ksi. The nominal chamber volume is 1945 cc minus the volume of the igniter vent assembly, and is equipped with six (6) access ports to monitor pressure and/or light generation response during ignition and flame spreading.
3. Mixing Chamber: The mixing chamber is connected to the combustion chamber via a control nozzle (variable in size and replaceable) and serves the function of mixing the combustion gases exiting from the combustion chamber as well as controlling the combustion chamber p-t profile.
4. Auxiliary Test Chamber. The auxiliary test chamber is a combustion gas diagnostic section designed to permit determination of the composition and enthalpy level of the gases exiting the propellant bed.
5. Blowdown Nozzle. The blowdown nozzle permits venting of the entire system and is installed with a burst diaphragm or a constant area bleed vent.



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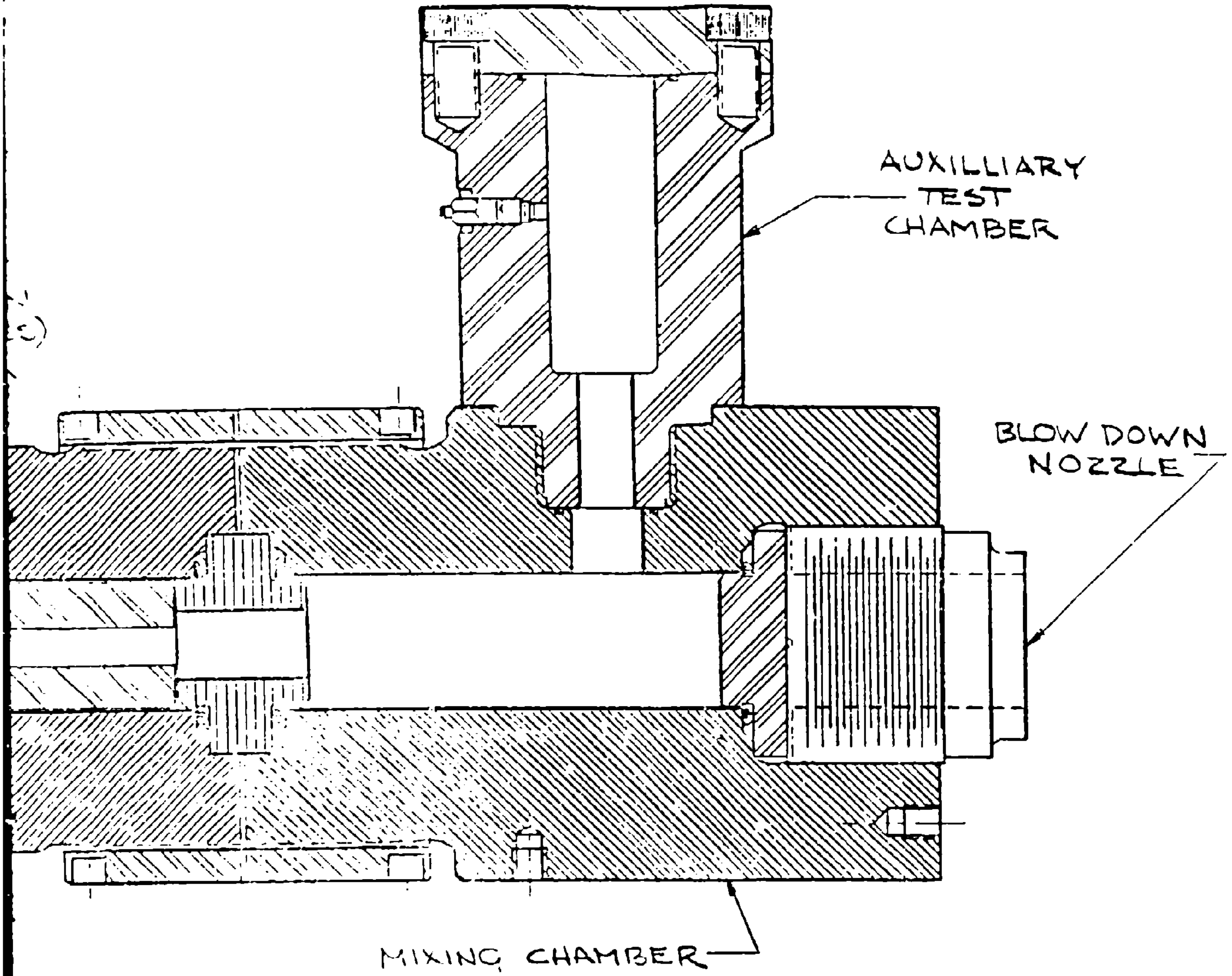

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DRAWN A. BRYANT 2-12-81
ISSUED

Applied Combustion Technology Inc
29 Coburn Ave. • Orlando, FL 32805
A Subsidiary of Mechtron International Corporation

IECD ASSEMBLY

SIZE	FSCM NO.	DWG. NO.	REV
B		FIGURE 2.1	
SCALE:		SHEET	

The IECD assembly is supported upon an ajustable test base, Figure 2.2, which facilitates igniter removal/assembly and propellant loading.

2.2 Igniter Characteristics

2.2.1 Baseline Igniter

The igniter system, Figure 2.3, is designed to provide overall event sequencing for data acquisition while facilitating some general design variations which could be easily achieved without extensive rework during the igniter testing and development. Toward this objective, an Olin Corporation M52A381 electric primer was chosen as the base element in the ignition train. To provide some flexibility in choice of igniter materials, an axial vent igniter with a cavity volume of 1 in^3 (16.39 cc) was designed with provisions for up to 5 axial vents. Individual vents consist of a No. 10-32 tapped hole in the velocity control element, each of which can be fitted with a pre-drilled (or blank) Allen-head set screw. This technique permits the easy variation of vent diameter from test to test and/or the replacement of eroded vents. The center vent has been oversized to accept a PCB-111A (10,000 psi) transducer to permit primer calibration and primer/igniter coupling calibration. In this manner, pressure profiles for the primer and the various igniter materials can be acquired for calibration and data correlation.

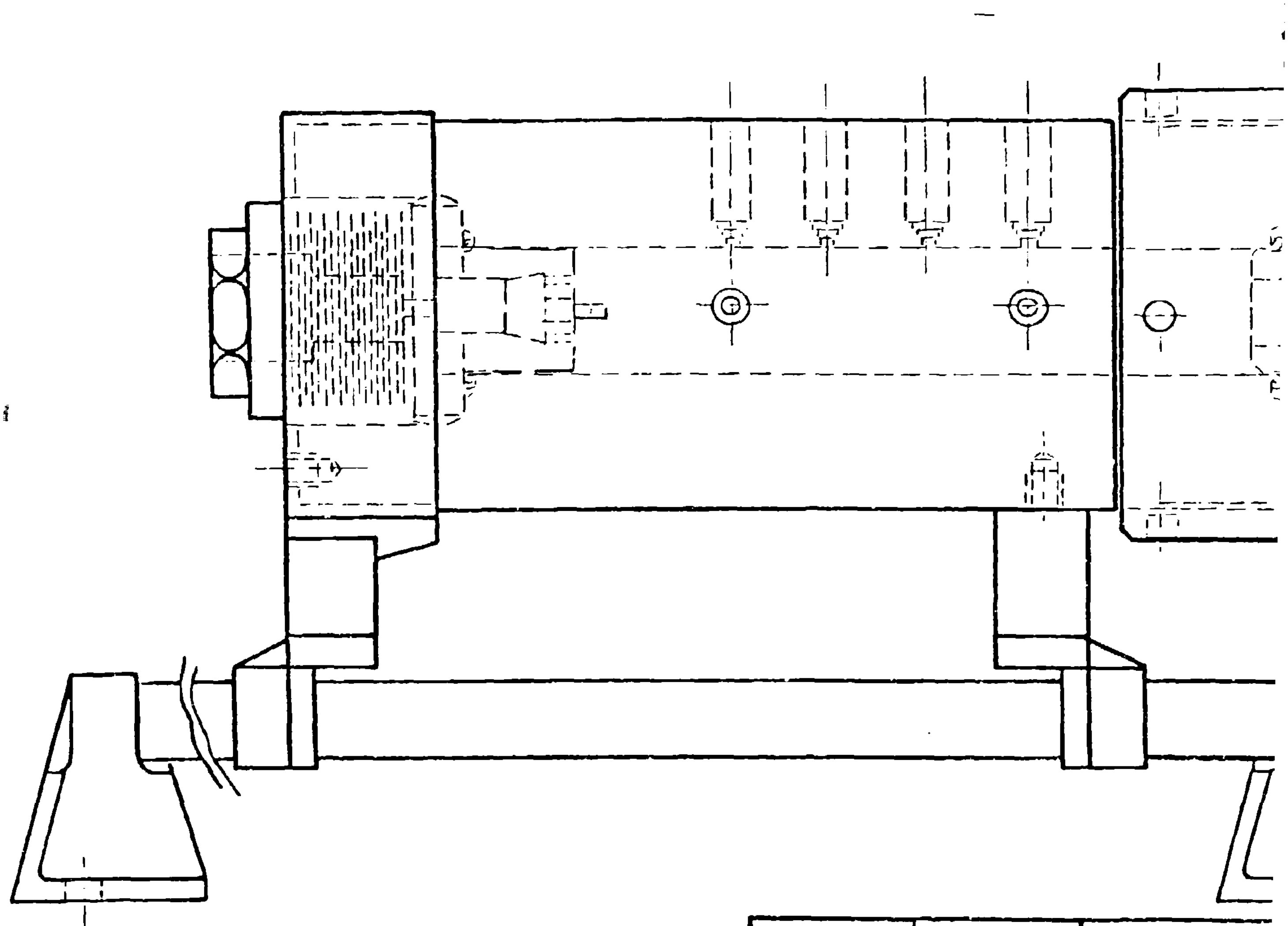
2.2.2 Calibration Data

Primary control variables available for the igniter development tests consisted of:

1. Axial vent variations in outflow area
2. Igniter material type
3. Igniter material quantity

As described earlier, axial vent outflow variations were achieved by selecting the outflow orifice size desired for up to five outflow elements. This type of variation permits control over

DWG N



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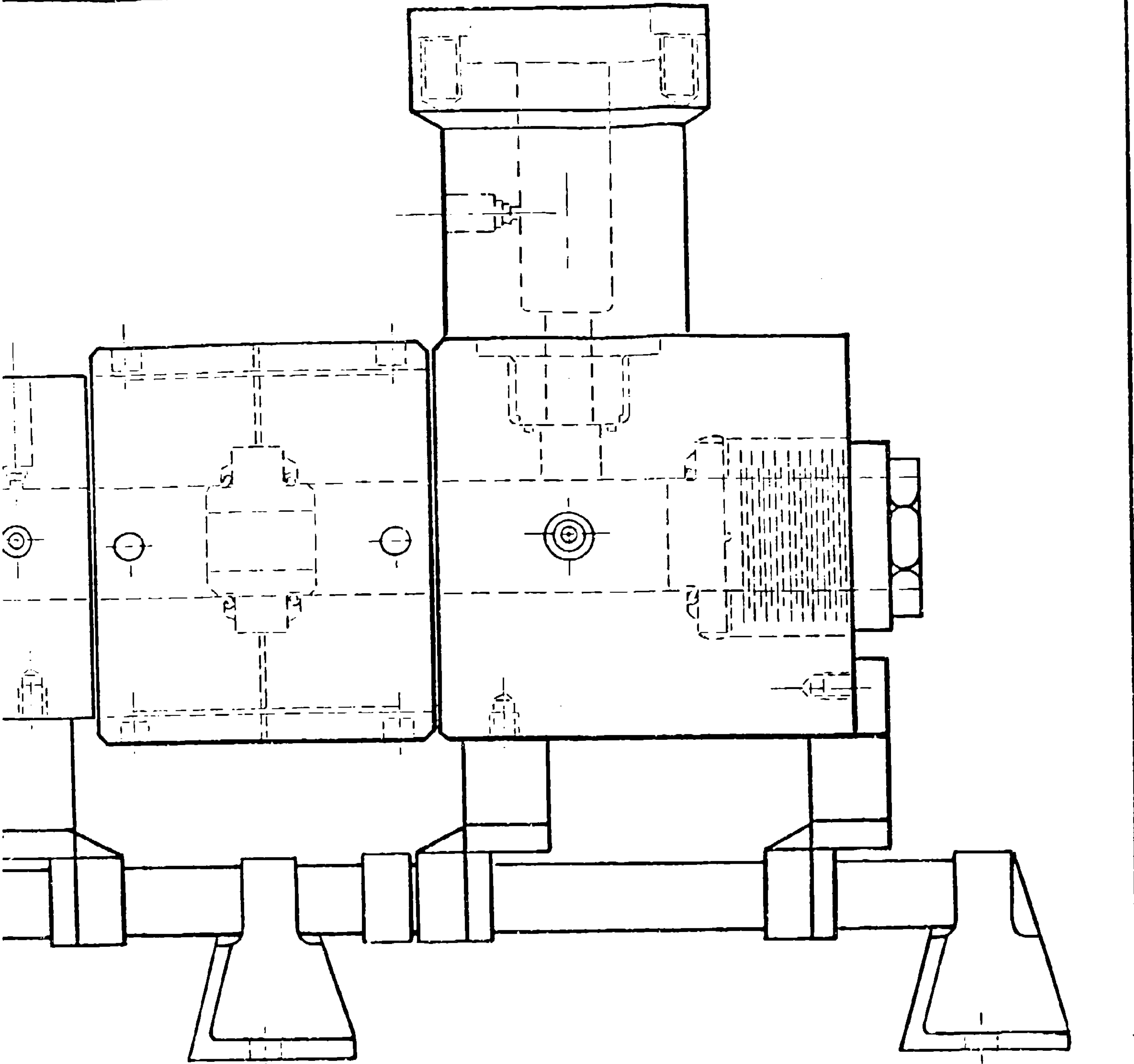

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UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONS ± 3 PLACE DECIMALS ± 2 PLACE DECIMALS ±		Applied Combustion Technology Inc. 29 Coburn Ave • Orlando, FL 32805 A Subsidiary of Mechtron International Corporation	
		IECD SUPPORTING STAND	
MATERIAL	DRAWN A. BRYANT 2-19-87	SIZE B | FSCM NO. | DWG. NO. FIGURE 2.2	REV
	ISSUED	SCALE:	SHEET

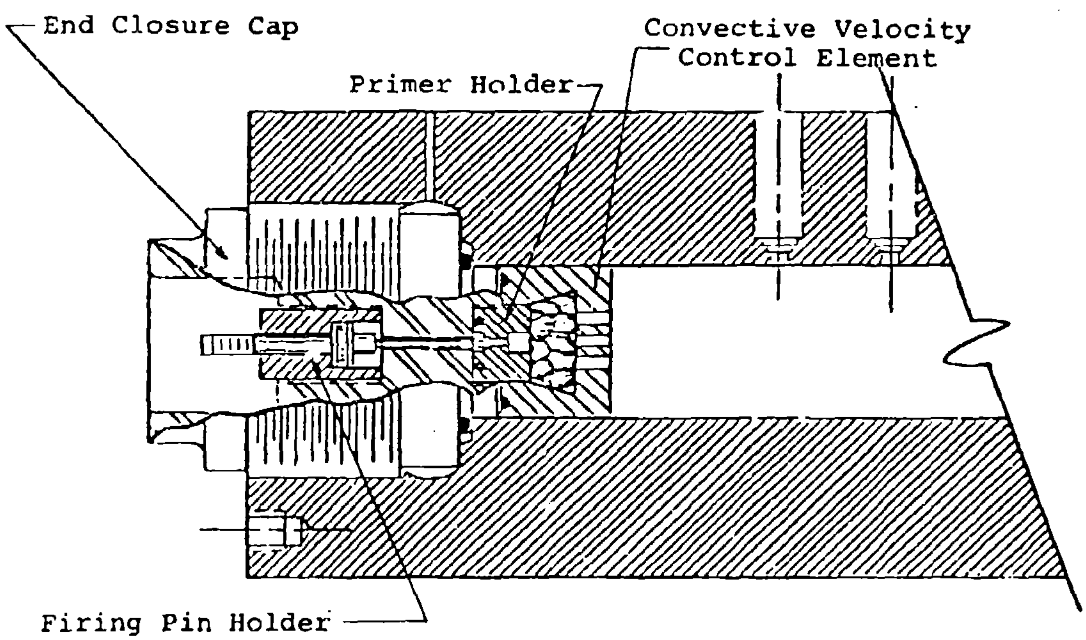


Figure 2.3 Igniter Assembly

the output velocity and mass flow delivered to the propellant bed. The igniter materials used in the test series consisted of commercially available black powder (Goex, Inc.), $BKNO_3$ pellets, $BKNO_3$ granules, and IMR 4895. Igniter material quantities of 1 gram and 2 grams were selected for calibration testing.

Using these combinations of control variables, 74 igniter calibration and development tests have been conducted with the IECD and are listed below:

IGNITER CALIBRATION TESTS

Number of Tests	Test Purpose	Primer	Vent	Igniter Material	Mass (gram)
15	Shakedown	Elec	4-080	BP	1
4	Primer Output	Elec	4-080	-	-
4	Primer Output	Elec	2-080	-	-
4	Igniter Function	Elec	4-080	BP	1
2	Igniter Function	Elec	2-080	BP	1
4	Igniter Function	Elec	4-080	BP	2
2	Igniter Function	Elec	2-080	BP	2
4	Igniter Function	Elec	4-080	$BKNO_3$-G	1
2	Igniter Function	Elec	2-080	$BKNO_3$-G	1
4	Igniter Function	Elec	4-080	$BKNO_3$-G	2
2	Igniter Function	Elec	2-080	$BKNO_3$-G	2
4	Igniter Function	Elec	4-080	$BKNO_3$-P	1
2	Igniter Function	Elec	2-080	$BKNO_3$-P	1
4	Igniter Function	Elec	4-080	$BKNO_3$-P	2
2	Igniter Function	Elec	2-080	$BKNO_3$-P	2
4	Igniter Function	Elec	4-080	NC	1
5	Igniter Function	Elec	2-080	NC	1
3	Igniter Function	Elec	4-080	NC	2
3	Igniter Function	Elec	2-080	NC	2

Vent designations of 4-080 and 2-080 refer to the number of outflow axial vents of 0.080-inch diameter, whereas $BKNO_3$ designations of "G" and "P" refer to granular and pellets, respectively.

Data acquisition for each primer function test and igniter function test consisted of a tabulation of the control variables and a photographic record of the pressure-time history recorded by a transducer located in the centerline vent position of the convective control element. Pressure-time profiles, typically shown in Figure 2.4, were acquired for:

1. Primer Function Test Data
2. Igniter Function Test Data: Black Powder
3. Igniter Function Test Data: $BKNO_3$ Granules
4. Igniter Function Test Data: $BKNO_3$ - Pellets
5. Igniter Function Test Data: NC

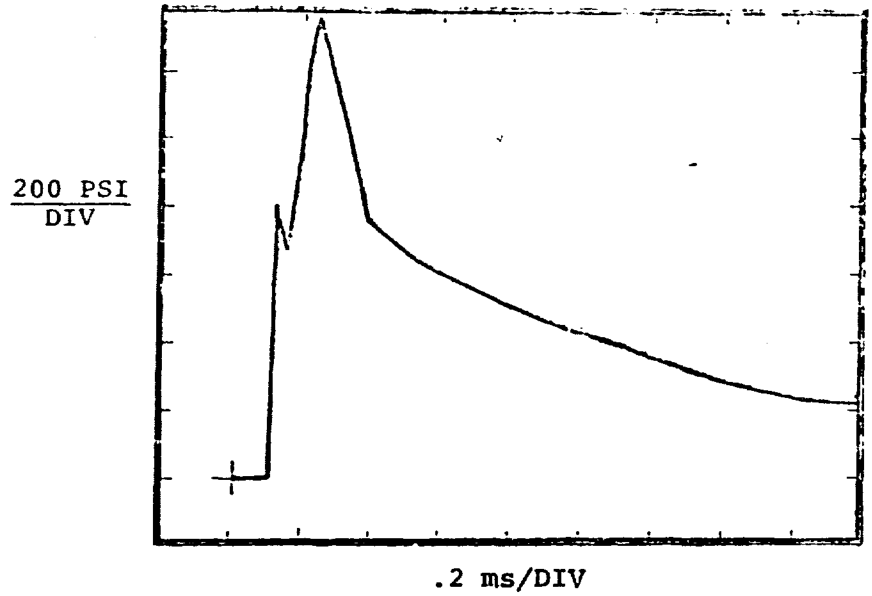
Each primer function pressure-time record, Figure 2.4a, was analyzed for:

1. Ignition delay time referenced with respect to event signal initiation
2. Pressurization rate
3. Peak pressure
4. Time to reach peak pressure
5. Overall event duration.

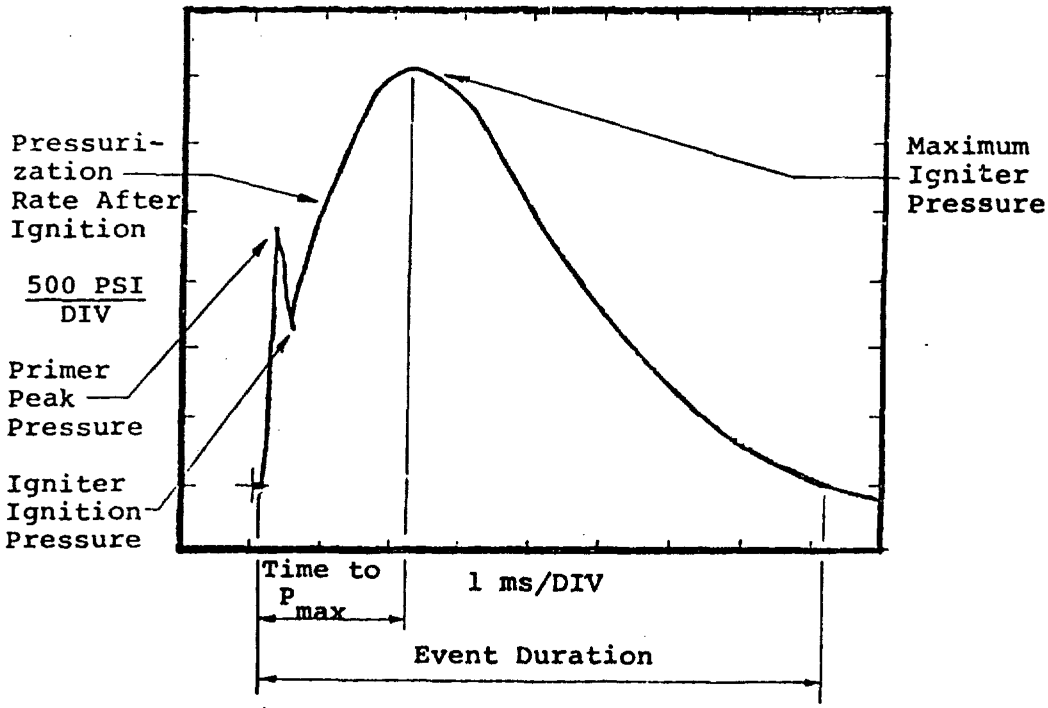
Each igniter function test, Figure 2.4b, was analyzed for:

1. Primer peak pressure
2. Igniter material ignition pressure
3. Igniter material pressurization rate
4. Peak igniter pressure
5. Time to reach peak igniter pressure
6. Total mass flow in gas phase exiting from convective control element
7. Event duration.

Composite summaries of the igniter data are presented in Tables I-V.



a. Primer Function Test



b. Igniter Function Test

Figure 2.4 Pressure-time profiles showing important highlights considered in igniter analysis

Table I. Electric Primer Data Summary

	ELECTRIC PRIMER			
	4 Holes		2 Holes	
Initiation Delay Time (ms)	.09		.15	
	.11		.14	
	.11		.11	
	.20			
	.12			
$\dot{P}$ Average (psi/ms)	9,259		10,007	
	11,609		10,191	
	16,985		9,623	
	6,200			
	10,042			
Primer Peak Pressure (psi)	1,500		1,401	
	1,428		1,528	
	1,080		1,443	
	1,402			
	1,407			
t at P_{max} (ms)	.162		.14	
	.123		.15	
	.154		.15	
	.15			
	.14			
Duration Time (ms)	2.88[1]		5.43[1]	
	.94[1]		3.95[1]	
	.63		3.77[1]	
	1.65[1]			
	1.82[1]			

[1]Estimated Duration Time

Table II. Black Powder Data Summary

	BLACK POWDER			
	4 holes		2 holes	
	1 gram	2 grams	1 gram	2 grams
Primer Peak (PSI)	1835	1818	1675	1385
	1510	2596	1765	1156
	1485	1377	1500	
		1298	1100	
		1886	1254	
			1255	
Igniter Ignition Pressure (PSI)	926	1084	831	1017
	771	1188	926	853
	928	944	856	
		930	676	
		1071	627	
			719	
$\dot{P}$ Igniter (PSI/ms)	146	1485	393	1161.8
	-25	1723	218	1004
	213	857	466	
		925	49	
		1077	148	
			157	
P_{max} Peak Pressure (PSI)	1156	2587	1605	3473.7
	959	3061	1281	3148
	1241	2430	1605	
		2544	1138	
		2500	1279	
			1495	
t at P_{max} (ms)	1.7	1.88	2.91	3.07
	3.1	1.82	2.25	3.22
	2.11	2.50	2.53	
		2.45	5.00	
		1.82	4.3	
			3.9	
Gas Phase (Mass) (grams)	.549	1.17	.46	1.03
	.546	1.32	.27	.91
	.625	1.06	.38	
		1.13	.39	
		1.16	.22	
			.23	
Ignition Duration Time (ms)	7.35	8.04	9.1	10.7[1]
	8.18	7.66	6.2	10.4[1]
	7.78	7.67	7.06	
		7.42	11.2[1]	
		7.40	7.9[1]	
			8.0[1]	

[1]Estimated Duration Time

Table III. $BKNO_3$-G Data Summary

	$BKNO_3$ (Granular)			
	4 holes		2 holes	
	1 gram	2 grams	1 gram	2 grams
Primer Peak (PSI)	1486	1576	1928	1300
	1421	1813	1724	1503
	1060	1735	1631	1735
Igniter Ignition Pressure (PSI)	909	1199	1270	975
	930	1544	1254	856
	690	1605	1152	986
$\dot{P}$ Igniter (PSI/ms)	1388	2099	1131	2065
	676	2321	1520	1908
	530	2031	485	1593
P_{max} Peak Pressure (PSI)	1486	2768	1823	2593
	1206	3054	1975	2876
	1204	3052	1524	3083
t at P_{max} (ms)	.90	1.64	1.10	1.61
	1.17	1.23	1.55	2.15
	1.80	1.38	1.85	2.56
Gas Phase Mass (grams)	.49	1.00	.43	.40
	.47	1.00	.45	.68
	.52	1.02	.38	.74
Ignition Duration Time (ms)	6.76	7.33	8.81	5.70
	7.88	7.00	8.82	10.00
	8.60	7.08	9.709	9.33

Table IV. $BKNO_3$-P Data Summary

	$BKNO_3$ (Pellets)			
	4 holes		2 holes	
	1 gram	2 grams	1 gram	2 grams
Primer Peak (PSI)	1216	1242	1727	1486
	1498	1345	1561	1427
	1289	1600	1473	1340
				1779
				1448
				1477
Igniter Ignition Pressure (PSI)	766	885	952	853
	817	837	842	1138
	758	935	821	1003
				1019
				868
				859
$\dot{P}$ Igniter (PSI/ms)	-367	-243	-471	-77
	-355	-116	-268	294
	-289	174	-198	215
				100
				-275
				-181
P_{max} Peak Pressure (PSI)	766	940	952	877
	817	1077	842	1810
	758	1363	821	1656
				1558
				868
				859
t at P_{max} (ms)	.28	4.70	.24	5.17
	.17	5.00	.22	5.8
	.20	4.9	.28	5.9
				5.2
				.22
				.29
Gas Phase Mass (grams)	.28	.42	.23	.35
	.31	.80	.26	.64
	.32	.93	.26	.58
				.53
				.19
				.24
Ignition Duration Time (ms)	11.9[1]	No Data	No Data	11.78
	11.0[1]	No Data	No Data	No Data
	11.0[1]	No Data	No Data	No Data
				No Data
				10.5[1]
				10.9[1]

[1]Estimated Duration Time

Table V. NC Data Summary

	Nitrocellulose			
	4 holes		2 holes	
	1 gram	2 grams	1 gram	2 grams
Primer Peak (PSI)	2000 1984 2419 2082	2268 2375 1423	1500 3128 2670 1690 1442	1548 2000 2633
Igniter Ignition Pressure (PSI)	925 1142 1023 943	1299 1121 990	872 987 1067 952 832	1138 1245 946
$\dot{P}$ Igniter (PSI/ms)	No Data 134.4 68.0 201.0	1780 555 760	573.3 623.4 285.8 555.0 330.0	320 633 765
P_{max} Peak Pressure (PSI)	1170 1165 1030 970	No Data 3380 3025	No Data No Data No Data 2340 1735	9000[2] 10106 9608
t at P_{max} (ms)	.21 .38 .35 .38	No Data 6.90 7.60	No Data No Data No Data 8.1 9.5	5.55 4.68 4.75
Mass at P_{max} (grams)	.095 .20 .18 .16	No Data 1.74 1.65	No Data No Data No Data .91 .69	1.80 1.95 1.84
Igniter Duration Time (ms)	2.16 3.16[1] 3.32[1] 3.20[1]	No Data 10.87 11.83[1]	No Data No Data No Data 14.1[1] 14.6	10.25 9.07 8.95

[1]Estimated Duration Time

[2]Estimated Peak Pressure

The p-t data acquired during the igniter development tests have been used as the basis to calculate the mass flow exiting the vents in the gas phase. The difference between the igniter mass initially loaded into the convective velocity control element and that amount exiting in the gas phase is presumed to be in the condensed phase; no conclusions as to whether the condensed phase material is burned or unburned at the vent exit were possible from this test series, although some unburned igniter material was found in the IECD tests with NC.

The total mass flow (gas phase) exiting from the vent was calculated using an ideal mass flow for a choked flow process

$$\frac{\dot{m}\sqrt{T_T}}{P_T A} = fn(M,\gamma)$$

where $\dot{m}$ = mass exit flow

T_T = total temperature of gas flow

P_T = total pressure of gas flow

A = exit flow area

In the calculations, it was assumed that the total temperature of the gases was equal to T_p at 1000 psia and that the total pressure was given according to the p-t curve. Property values used in the calculations are given below:

Item	BP	BKNO3	NC
Igniter Mass (Initial)	1,2 g	1,2 g	1,2 g
T_p @ 1000 psia	$1977^{\circ}K$	$2998^{\circ}K$	$2593^{\circ}K$
M	57.4	63.9	24.7
γ	1.15	1.19	1.22
p-t record	Data	Data	Data

The total mass outflow was obtained by integrating the p-t record, according to

$$m_{gas} = \frac{fn(M,\gamma)A}{\sqrt{T_T}} \int_0^{\tau} P(t)dt$$

Tabular integrations were performed from the data and indicate the following ratios for condensed outflow with the gases:

			Exit Flow Mass (gm)		
Igniter	Mass (gm)	Vent	Gases	Condensed	M_g/M_i
BP	1	4-080	.57	.43	.57
	2	4-080	1.25	.75	.63
	1	2-080	.35	.65	.35
	2	2-080	.97	1.03	.48
$BKNO_3$(G)	1	4-080	.49	.51	.49
	2	4-080	1.01	.99	.51
	1	2-080	.42	.58	.42
	2	2-080	.61	1.39	.30
$BKNO_3$(P)	1	4-080	.30	.70	.30
	2	4-080	.72	1.28	.36
	1	2-080	.25	.75	.25
	2	2-080	.42	1.58	.21
NC	1	4-080	.18	.82	.18
	2	4-080	1.70	.30	.85
	1	2-080	.80	.20	.80
	2	2-080	1.86	.14	.93

These results indicate that the BP exit mass flow is approximately 50 percent in the gas phase whereas the $BKNO_3$ (granular) has a slightly higher concentration of condensed phase material. The NC igniter data indicate that 85 percent is in the gas phase and 15 percent is in the condensed phase. These calibration data will provide a partial basis for interpreting the NACO ignition effectiveness tests presented in the following section.

2.3 NACO Ignition Effectiveness

2.3.1 Experimental Program

The NACO ignition effectiveness experimental program utilized the IECD with three variable length zones of inert simulant and NACO grains, as previously shown in Figure 2.1. Inert simulant was contained in Zone 1 and was positioned immediately downstream of the igniter exit vents to provide a non-combustible porous bed between the igniter output and the NACO. The Zone I bed thickness, l_1, was varied in the test program and provided a means for extending the ignition event in the time plane, as well as providing a mechanism (blockage) for limiting the amount of condensed phase materials which impinged directly on the NACO propellant positioned in Zone 2. Zone 2 of the IECD contained 40 grams of NACO propellant which was held in place by a layer of inert simulant designated as Zone 3. All propellant loading was done with the IECD in the vertical position using weighed quantities of Zone I inert simulant, Zone 2 live NACO, and Zone 3 inert simulant; grain bulk motion was prevented by using a ported end vent which filled the void in the IECD, permitting the normal IECD end cap to be utilized for the test series.

The IECD test program consisted of three main elements:

1. Primer Penetration Tests,
2. Igniter Penetration Tests, and
3. Igniter Effectiveness Tests.

The <u>primer penetration tests</u> were conducted to determine the minimum thickness of inert simulant in Zone 1 which permitted isolation of the primer (only) output from the Zone 2 NACO propellants. These tests were conducted to insure that the primer effects could be filtered out by the Zone 1 inert simulant and not bias the minimum igniter energy effectiveness test boundary which was to be developed later in the program.

The igniter penetration tests were conducted to establish the maximum thickness of Zone 1 inert simulant for which NACO ignition could not be achieved using a baseline igniter energy level of 1368 calories for BP, $BKNO_3$, and NC. By varying the Zone 1 inert simulant thickness, l_1, from zero thickness to a large value of l_1 for the no-ignition boundary, the ignition effectiveness of NACO for a fixed igniter energy level is documented as a function of increased heat loss of the igniter products prior to flowing into the Zone 2 live NACO grains. The increased thickness of Zone 1 inert simulant would result in increased gas phase heat transfer losses to the inert grains and subsequently, less energy being available to the NACO zone from the gas phase. This argument is based upon the belief that the higher thermal inertia of the condensed phase liquids and solids would persist longer while being convectively driven through the Zone 1 inert simulant bed.

The igniter effectiveness tests were conducted to establish the minimum igniter energy level for which NACO ignition could not be achieved for a fixed thickness of Zone 1 inert simulant. The thickness of the Zone 1 inert simulant was selected, based upon the igniter penetration test results, to be 30 percent less than the no-ignition thickness condition for the least effective igniter material. By holding the Zone 1 thickness constant and gradually reducing the igniter energy level, a low-energy no-ignition boundary is established as a function of a decreased convective velocity environment. It is felt that these tests would be able to separate the condensed phase effects upon NACO ignition since the condensed igniter solids would be more mobile in the inert simulant zone, whereas the action of condensed liquids would be more quickly degraded because of the mass loss due to wetting the inert simulant upstream of the NACO grains.

2.3.2 NACO Ignition Data

The experimental program described in the previous section consisted of 46 test firings, as presented in the run log, Appendix A, and concentrated upon establishing the NACO ignition delay time with respect to the primer signal, Figure 2.5. As can be seen in the figure, a major advantage of the IECD inert simulant in Zone 1 is being able to separate the primer event from the NACO combustion event by several seconds. Values of peak pressure in the NACO bed ranged from 2500 psi to 3500 psi for the test series and were generally independent of Zone 1 inert simulant bed thickness and igniter energy level.

Oscilloscope records of firings with BP, $BKNO_3$, and NC are shown in Figure 2.6 to indicate the general quality of the data; all data records are included in Appendix B. Ignition delay data and peak pressure data for the igniter penetration tests and the igniter effectiveness tests are presented in Tables VI and VII, respectively.

Igniter penetration test firings were conducted for BP, $BKNO_3$, and NC igniter materials at an energy level of 1368 calories for Zone 1 inert simulant thickness of 0.0, 0.75, 1.50, 2.00, and 2.50 inches. All igniters initiated NACO at 0.0, 0.75, and 1.50 inches; however, only $BKNO_3$ resulted in NACO ignition for Zone 1 inert simulant thickness levels of 2.00 and 2.50 inches. Although not enough test firings were conducted at each test condition to justify averages, engineering best-fit ignition delay time and peak pressure data have been plotted as a function of bed length in Figure 2.7. These limited results indicate that $BKNO_3$ igniter material has the lowest ignition delay time, followed by BP and NC. Using best-fit engineering curves, the $BKNO_3$ ignition delay was 1.5 seconds at a bed length of 2.0 inches. In order to achieve a comparable ignition delay time for BP and NC, the bed length of inert simulant would have to be reduced to

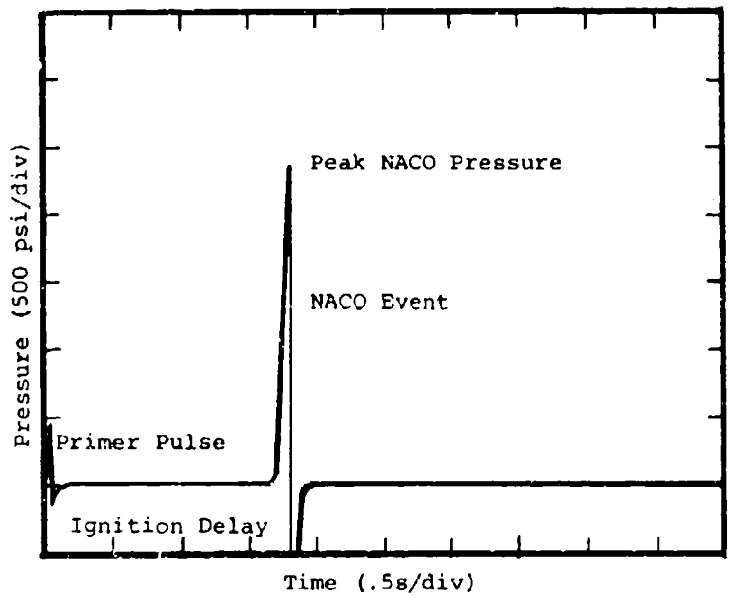
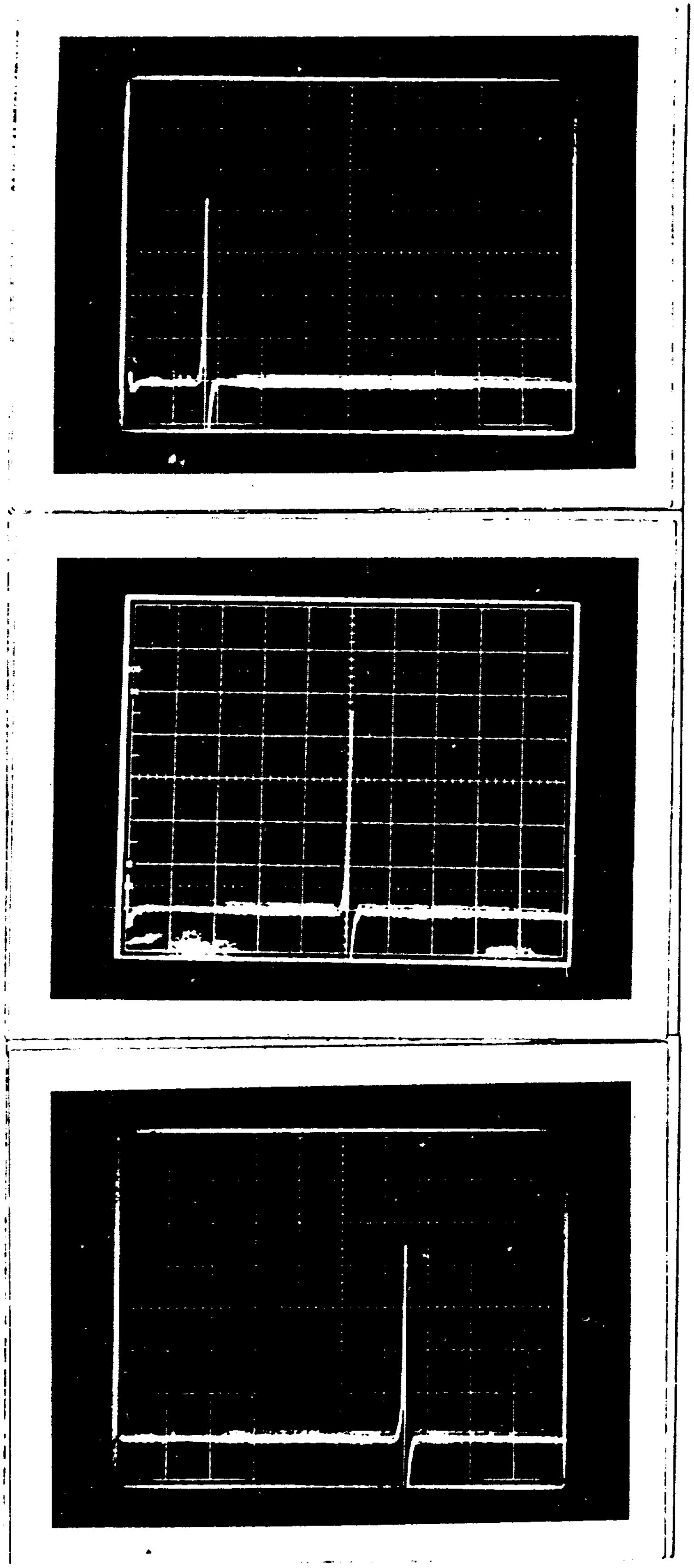


Figure 2.5 IECD Pressure-time Profile Showing Primer Pulse and NACO Combustion



Test No. 021
$BKNO_3$
1368 calories
l_1 = 1.5 in
T = 0.80 s
P_{max} = 2200

Test No. 019
BP
1368 calories
l_1 = 1.5 in
T = 2.45 s
P_{max} = 2300

Test No. 020
NC
1368 calories
l_1 = 1.5 in
T = 3.16
P_{max} = 2300

Figure 2.6 Pressure-time Records for NACO Propellant with $BKNO_3$, BP, and NC Igniters

Table VI. Igniter Penetration Tests: Fixed Igniter Energy Content (1368 Calories)

l_1 (in)		Black Powder	$BKNO_3$	Nitrocellulose
0.75		#16	#18	#17
	t_d	1.17 sec.	0.024 sec.	1.21 sec.
	P_{max}	2,950 psi	3,380 psi	2,930 psi
1.50		#19	#21	#20
	t_d	2.45 sec.	0.80 sec.	3.16 sec.
	P_{max}	2,330 psi	2,190 psi	2,330 psi
		#38	#44	#41
	t_d	1.33 sec.	1.71 sec.	2.41 sec.
	P_{max}	3,050 psi	2,080 psi	$\gtrsim$>3,500 psi
		#39	#45	#42
	t_d	1.87 sec.	1.78 sec.	2.48 sec.
	P_{max}	2,550 psi	$\gtrsim$>3,500 psi	2,160 psi
		#40	#46	#43
	t_d	3.10 sec.	1.32 sec.	2.58 sec.
	P_{max}	1,960 psi	2,990 psi	$\gtrsim$>3,500 psi
2.00		#22	#24	#23
	t_d	No NACO ign. Good ign. output	1.30 sec.	No NACO ign., Weak ign. output, Some unburnt N.C. in Comb. Chamber ~10%
	P_{max}		2,070 psi	
2.50			#25	
	t_d		1.08 sec.	
	P_{max}		$\gtrsim$>3,500 psi	

Note:

- Test Number

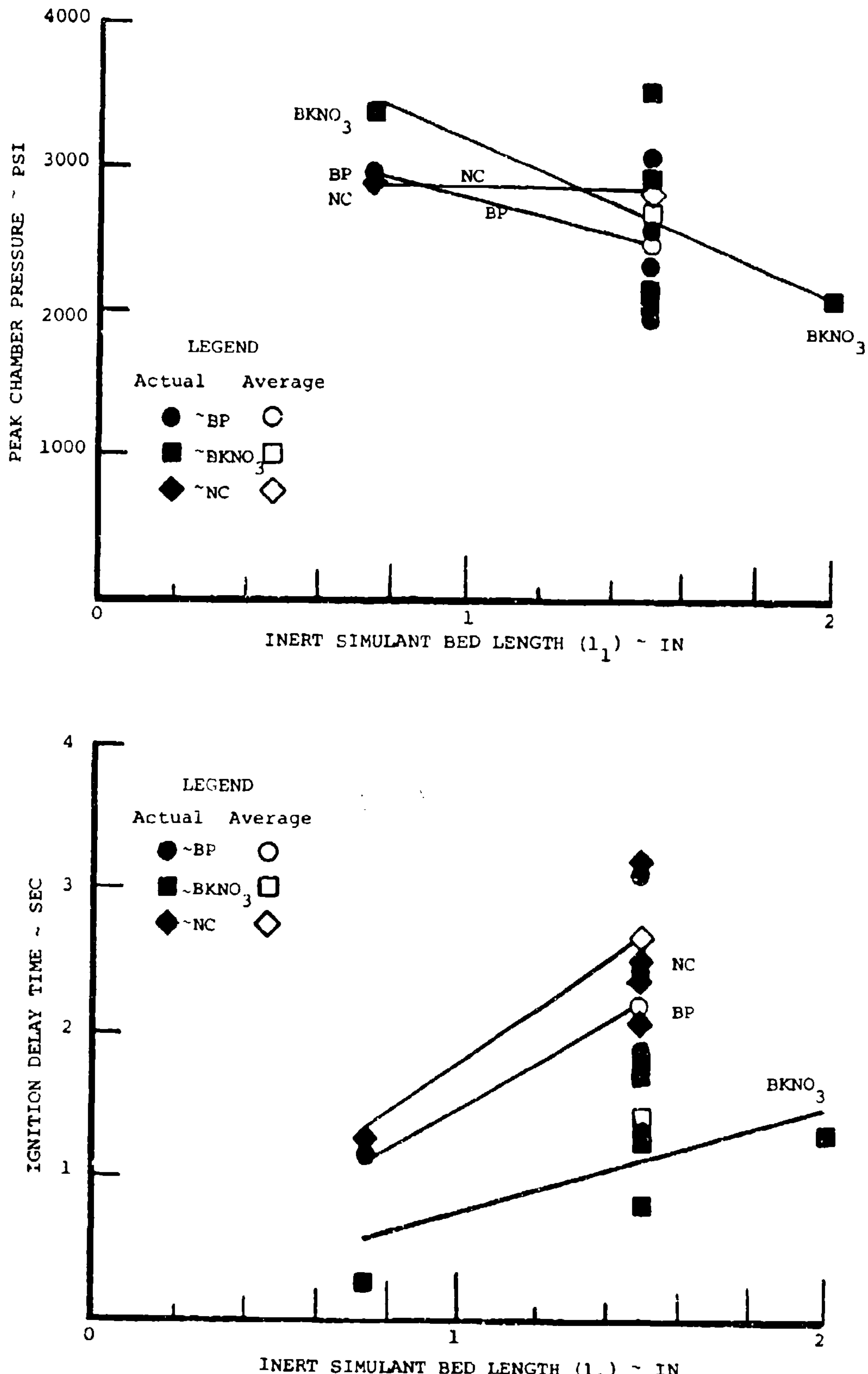
t_d - Ignition Delay Time

P_{max} - Peak NACO Combustion Pressure

Table VII. Igniter Effectiveness Tests: Fixed Zone 1 Distance (1.50 inches)

Energy (Calories)		Black Powder	$BKNO_3$	Nitrocellulose
1368		#19	#21	#20
	t_d	2.45 sec.	0.80 sec.	3.16 sec.
	P_{max}	2,330 psi	2,190 psi	2,330 psi
		#38	#44	#41
	t_d	1.33 sec.	1.71 sec.	2.41 sec.
	P_{max}	3,050 psi	2,080 psi	≈>3,500 psi
		#39	#45	#42
	t_d	1.87 sec.	1.78 sec.	2.48 sec.
	P_{max}	2,550 psi	≈>3,500 psi	2,160 psi
		#40	#46	#43
	t_d	3.10 sec.	1.32 sec.	2.58 sec.
	P_{max}	1,960 psi	2,990 psi	≈>3,500 psi
1100		#26	#29	#27-28
	t_d	2.00 sec.	1.47 sec.	No NACO ign., N.C. found un-
	P_{max}	2,900 psi.	2,560 psi	burnt in igniter housing
900		#30	#31	
	t_d	2.27 sec.	1.83 sec.	
	P_{max}	2,490 psi	2,630 psi	
700		#32	#33	
	t_d	2.30 sec.	2.31 sec.	
	P_{max}	≈>3,500 psi	2,150 psi	
500		#34	#35	
	t_d	2.41 sec.	3.00 sec.	
	P_{max}	2,900 psi	3,200 psi	
300		#36	#37	
		No NACO ign.	No NACO ign. Soft ign. noise	

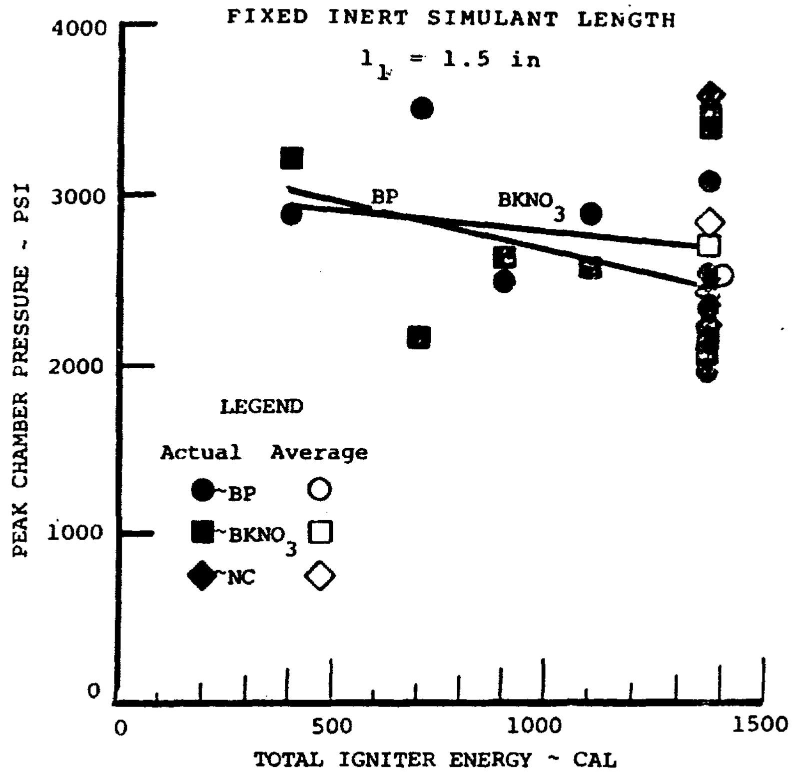
Figure 2.7 Igniter Penetration Test Data

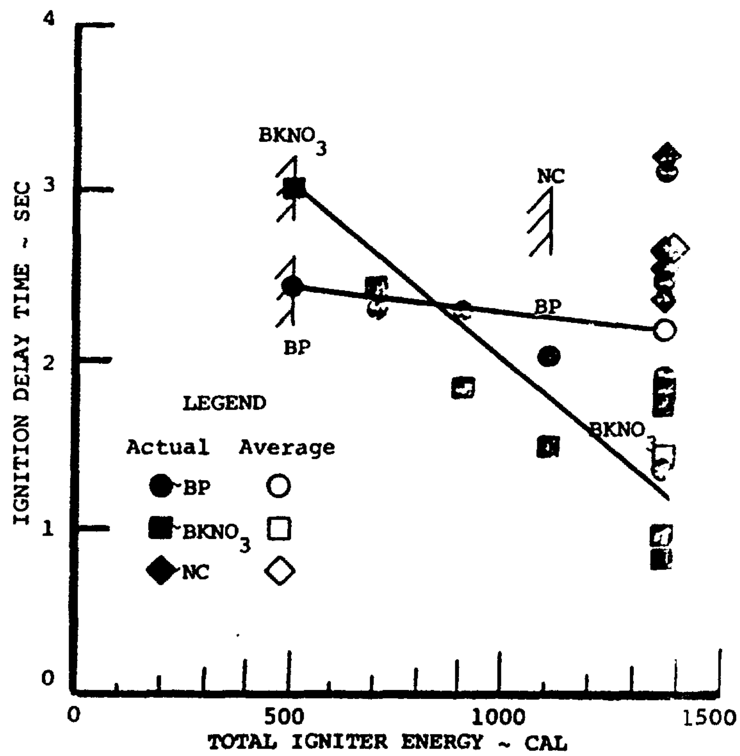


1 inch and 0.8 inch, respectively. These data suggest that $BKNO_3$ is approximately twice as effective in igniting NACO grains in the IECD as BP and NC. Again, using best-fit curves to the data, the values of peak pressure measured in the IECD decrease as the bed length of inert simulant increases in Zone 1. Since the total length of zones 1, 2, and 3 was held constant for the test series, this observation would suggest that the upstream volume in Zone 1 is more readily available to the NACO combustion products expansion than the downstream Zone 3 region. One possible explanation--supported by post-test observations--is that the Zone 3 inert simulant is partially melted by the NACO forming a porous plug which acts as a partial seal to the outlet gas flow, thus reducing the combustion gas free volume.

Igniter effectiveness test firings were conducted for BP, $BKNO_3$, and NC igniter energy levels of 1368, 1100, 900, 700, 500, and 300 calories for a fixed zone 1 inert simulant thickness of 1.50 inches. $BKNO_3$ and BP igniters were capable of initiating NACO combustion at energy levels as low as 500 calories, but were both unsuccessful at 300 calories. NC was not successful in igniting NACO at 1100 calories of energy input. Ignition delay time and peak pressure data have been plotted as a function of igniter energy level in Figure 2.8. Best-fit engineering curves for these data indicate that the ignition delay time for $BKNO_3$ increases at a faster rate than BP as the igniter energy level is decreased. Since both igniters were effective in igniting the NACO bed, the increase in ignition delay time suggests that the BP is more effective than the $BKNO_3$ at the lower energy level. Since the igniter cavity was designed for a larger quantity of material, these differences may be a result of the hardware and not a result of the igniter material. Future tests will be conducted with a reduced size igniter to isolate these apparent low-energy effects. The peak pressure data, also shown in Figure 2.8, are relatively insensitive to igniter energy levels.

Figure 2.8 Igniter Effectiveness Test Data





2.4 Data Analysis

Based upon the data presented in the previous section, the relative igniter effectiveness, from the most effective to the least effective, may be stated as:

1. Boron potassium nitrate ($BKNO_3$)
2. Black powder (BP)
3. IMR 4895 (NC)

A fundamental analytical presentation is offered in this section as a means of interpreting the experimental data.

If one envisions the igniter exhaust products passing through a randomly oriented bed of right circular cylinders (inert simulant and NACO) contained in the bore of the IECD, then the process of igniting the live propellant bed can be viewed in terms of the time required to produce a sustaining exothermic chemical reaction in the live propellant. Two factors which influence the time to produce sustaining reactions are the rate at which the propellant is heated and the chemical composition compatibility of the igniter products with the propellant. Since the three igniter materials produce products which are fuel rich, and the initial stages of NACO decomposition appear to be fuel rich, the rate at which energy is transferred to the NACO propellant surface appears to be the factor controlling the propellant ignition process. In the IECD experiments where the zone 1 inert simulant provides an inert upstream porous bed boundary for the live propellant, the contribution of radiation to NACO ignition can be neglected; consequently, NACO ignition may be viewed initially in terms of a convective heating process.

For forced convection through packed beds, the heat transfer coefficient, h, may be expressed as a function of grain diameter and thermodynamical properties in functional form by

$$\frac{hD}{k} = C_1 \left(\frac{D\rho V}{\mu}\right)^{\frac{1}{2}} \left(\frac{C_p \mu}{k}\right)^{\frac{1}{3}} \qquad (1)$$

where C_1 = empirical constant

D = grain diameter

k = igniter products thermal conductivity

ρ = igniter products density

V = igniter products velocity

μ = igniter products viscosity

C_p = igniter products specific heat

Of interest to the current analysis is the influence of the igniter combustion products upon the magnitude of the heat transfer coefficient, h, and ultimately on the convective heat transfer, q, to the propellant grains, given functionally by

$$q = hA(T_f - T_p)$$

where A = propellant grain heat transfer area

T_f = igniter products temperature

T_p = propellant surface temperature

Using the molecular definitions of the transport properties, equation (1) can be expressed in terms of thermodynamic properties to arrive at a qualitative ranking of the igniter materials' relative effectiveness. From Transport Phenomena by Bird, Stewart, and Lightfoot, viscosity, thermal conductivity and density may be expressed proportionally as:

$$\mu \sim (MT)^{\frac{1}{2}} \tag{2}$$

$$k \sim C_p T^{\frac{1}{2}} M^{-\frac{1}{2}} \tag{3}$$

$$\rho \sim M \tag{4}$$

$$V \sim C \tag{5}$$

where M is the molecular weight of the igniter products and C is the sonic velocity. Substituting equations 2, 3, 4, and 5 into equation (1) gives an expression for the heat transfer coefficient

$$h \sim C_1 C_p \mu^{\frac{1}{2}} M^{\frac{5}{6}} D^{\frac{1}{2}} C^{\frac{1}{2}} \qquad (6)$$

In order to evaluate the relative magnitude of the heat transfer coefficient for BP, $BKNO_3$, and NC, it is necessary to review the equilibrium characterization of the igniter material combustion products. Thermochemical equilibrium calculations have been generated for BP, $BKNO_3$, and NC at specified pressures and specified temperatures typical of the expected igniter performance range and are shown in Tables VIII through XIII. The data shown in the tables provide the transport properties necessary to evaluate equation 6, but provide no insight into the determination of the correlation constant C_1. For normal gas flow through packed beds, the value of C_1 is 0.6 and 0.81 for flow with saturated steam showing that if the flow field contains a liquid phase, the value of C_1 increases. To aid in the evaluation of C_1, additional data have been provided in Tables VIII through XIII as to the major mole fractions of the three igniter materials in the gas, liquid, and solid phases.

Black Powder (BP)

Thermochemical calculations for BP based upon an initial composition of 10 percent sulfur, 74 percent KNO_3, and 16 percent charcoal indicate that the igniter products are fuel rich and contain gases, liquids, and solids in the following mole fraction proportions:

	Peak Pressure	Expanded Pressure
Primary Gases	.70	.59
Minor Gases	.18	.36
Liquids	.12	Trace
Solids	Trace	.05

Table VIII

EQUILIBRIUM COMBUSTION CHARACTERIZATION OF IGNITER MATERIALS
AT SPECIFIED PRESSURE FOR BP

Item	500 PSI	1000 PSI	2000 PSI
Temperature (^{o}K)	1932	1977	2015
Specific Heat (Cal/g-k)	.62	.53	.47
Molecular Weight	56.1	57.4	58.6
Sonic Velocity (m/s)	564	562	560
Mole Fractions of Combustion Products	Sulfur 10%	KNO_3 74%	Charcoal 16%
Gases	CO_2	CO_2	CO_2
	.328	.312	.305
	CO	CO	CO
	.20	.20	.20
	H_2O	H_2O	H_2O
	.077	.081	.083
	N_2	N_2	N_2
	.174	.176	.178
Liquids	K_2S (L)	K_2S (L)	K_2S (L)
	.125	.121	.113
	K_2CO_3 (L)	K_2CO_3 (L)	K_2CO_3 (L)
	.025	.041	.058
	K_2SO_4 (L)	K_2SO_4 (L)	K_2SO_4 (L)
	.005	.002	-
Solids	Trace	Trace	Trace

Table IX

EQUILIBRIUM COMBUSTION CHARACTERIZATION OF IGNITER MATERIALS AT SPECIFIED PRESSURE FOR $BKNO_3$

Item	500 PSI	1000 PSI	2000 PSI
Temperature (^{o}K)	2915	2998	3082
Specific Heat (Cal/g-k)	1.6	1.5	1.3
Molecular Weight	62.6	63.9	65.2
Sonic Velocity (m/s)	646	648	651
Mole Fractions of Combustion Products	B 23.7%	KNO_3 70.7%	Laminac 5.6%
Gases	KBO_2	KBO_2	KBO_2
	.245	.252	.259
	CO	CO	CO
	.121	.121	.121
	B_2O_2	B_2O_2	B_2O_2
	.065	.060	.055
	N_2	N_2	N_2
	.035	.032	.029
Liquids	B(L)	B(L)	B(L)
	.175	.178	.178
Solids	BN(S)	BN(S)	BN(S)
	.201	.208	.217

Table X

EQUILIBRIUM COMBUSTION CHARACTERIZATION OF IGNITER MATERIALS AT SPECIFIED PRESSURE FOR NC

Item	500 PSI	1000 PSI	2000 PSI
Temperature (^{O}K)	2588	2593	2597
Specific Heat (Cal/g-k)	.46	.45	.44
Molecular Weight	24.7	24.7	24.7
Sonic Velocity (m/s)	1030	1032	1034
Mole Fractions of Combustion Products	NC 100%		
Gases	CO_2	CO_2	CO_2
	.128	.128	.128
	CO	CO	CO
	.42	.42	.42
	H_2O	H_2O	H_2O
	.225	.225	.225
	N_2	N_2	N_2
	.111	.111	.111
Liquids	Trace	Trace	Trace
Solids	Trace	Trace	Trace

Table XI

EQUILIBRIUM COMBUSTION CHARACTERIZATION OF IGNITER MATERIALS
AT SPECIFIED TEMPERATURE FOR BP

Item	250°K	1000°K	2000°K
Pressure (PSIA)	28	216	656
Specific Heat (Cal/g-°K)	.19	.81	.65
Molecular Weight	56	73	145
Sonic Velocity (m/s)	124	350	575
Mole Fractions of Combustion Products	Sulfur 10%	KNO_3 74%	Charcoal 16%
Gases	CO_2	CO_2	CO_2
	.156	.23	.319
	CO	CO	CO
	Trace	.145	.207
	H_2O	H_2O	H_2O
	Trace	.009	.075
	N_2	N_2	N_2
	.176	.207	.173
Liquids	K_2S(L)	K_2S(L)	K_2S(L)
	Trace	Trace	.121
	K_2CO_3(L)	K_2CO_3(L)	K_2CO_3(L)
	Trace	Trace	.026
Solids	C(S)	C(S)	C(S)
	.38	.02	Trace
	K_2SO_4(S)	K_2SO_4(S)	K_2SO_4(S)
	.15	Trace	Trace
	K_2CO_3(S)	$KNSO_3$(C)	K_2SO_3(S)
	.026	.027	Trace

Table XII

EQUILIBRIUM COMBUSTION CHARACTERIZATION OF IGNITER MATERIALS AT SPECIFIED TEMPERATURE FOR $BKNO_3$

Item	$250^{\circ}K$	$1000^{\circ}K$	$2000^{\circ}K$
Pressure (PSIA)	2	113	508
Specific Heat ($Cal/g-^{\circ}K$)	.19	.92	.90
Molecular Weight	1286	536	107
Sonic Velocity (m/s)	40	113	405
Mole Fractions of Combustion Products	B 23.7%	KNO_3 70.7%	Laminac 5.6%
Gases	KBO_2	KBO_2	KBO_2
	Trace	.018	.284
	CO	CO	CO
	Trace	Trace	.029
	CH_4	CH_4	CH_4
	.031	.012	Trace
	H_2	H_2	H_2
	Trace	.035	.061
Liquids	B_2O_3(L)	B_2O_3(L)	B_2O_3(L)
	.296	.275	.099
	K(L)	K(L)	K(L)
	Trace	.249	Trace
Solids	K(S)	K(S)	K(S)
	.28	Trace	Trace
	BN(S)	BN(S)	BN(S)
	.28	.28	.29
	C(S)	C(S)	C(S)
	.095	.109	.099

Table XIII

EQUILIBRIUM COMBUSTION CHARACTERIZATION OF IGNITER MATERIALS
AT SPECIFIED TEMPERATURE FOR NC

Item	$250^{o}K$	$1000^{o}K$	$2000^{o}K$
Pressure (PSIA)	89	487	1016
Specific Heat (Cal/g-^{o}K)	.26	.32	.42
Molecular Weight	64	30	25
Sonic Velocity (m/s)	193	563	911
Mole Fractions of Combustion Products	NC 100%		
Gases	CO_2	CO_2	CO_2
	.278	.328	.143
	CO	CO	CO
	Trace	.124	.402
	H_2O	H_2O	H_2O
	Trace	.189	.211
	N_2	N_2	NC
	.111	.120	.111
Liquids	H_2O(L)	H_2O(L)	H_2O(L)
	Trace	Trace	Trace
Solids	C(S)	C(S)	C(S)
	.267	.097	Trace

These results suggest that, if all of the igniter material were to be burned in the igniter housing, the exhaust products would be essentially hot gases with approximately 5 percent solids; consequently, the primary NACO ignition mode would be expected to be gas phase convective heating with some minor assistance from hot particle impact.

Boron Potassium Nitrate ($BKNO_3$)

Thermochemical calculations for $BKNO_3$ based upon an initial composition of 23.7 percent boron, 70.7 percent KNO_3, and 5.6 percent laminac indicate that the igniter products are fuel rich and contain gases, liquids, and solids in the following mole fraction proportions:

	Peak Pressure	Expanded Pressure
Primary Gases	.37	.07
Minor Gases	.14	.01
Liquids	.10	.53
Solids	.39	.39

These results suggest that, if all of the igniter material were burned in the igniter housing, the exhaust products would be over 50 percent liquids and 39 percent solids with the remaining 8 percent in the gas phase; consequently, the primary NACO ignition mode would be expected to be liquid phase convective heating with major assistance from hot particle impact.

Nitrocellulose (NC)

Thermochemical calculations for NC based upon an initial composition of 100 percent nitrocellulose indicate that the igniter products are fuel rich and contain gases, liquids, and solids in the following mole fraction proportions:

	Peak Pressure	Expanded Pressure
Primary Gases	.86	.76
Minor Gases	.14	.14
Liquids	Trace	Trace
Solids	Trace	.10

These results suggest that, if all of the igniter material were burned in the igniter housing, the exhaust products would be essentially hot gases with approximately 10 percent solids; consequently, the primary NACO ignition mode would be expected to be gas phase convective heating with some minor assistance from hot particle impact.

A comparison of these results indicates that BP and NC are primarily gases and would have a heat transfer correlation constant, C_1, value of 0.60. On the other hand, $BKNO_3$ has a large portion of liquids and solids in the exhaust stream and would be expected to have a value of C_1 higher than 0.60; however, since no data are available under these conditions, $BKNO_3$ will also be assigned a C_1 value of 0.60.

Using the data contained in the previous tables as a correlation constant of 0.60, the relative igniter effectiveness, based upon convective heat transfer would be predicted to behave as follows, according to equation (6),

$$h \sim C_1 C_p T^{\frac{1}{2}} M^{\frac{5}{6}} D^{\frac{1}{2}} C^{\frac{1}{2}}$$

	BP	$BKNO_3$	NC
C_p	.32	.92	.32
T_p at 1000	1,977	2,998	2,593
$T_p^{\frac{1}{2}}$	44.5	55.8	50.9
M	57.4	63.9	24.7
$M^{\frac{5}{6}}$	29.2	31.9	14.5
C_1	.6	.6	.6
C	562	648	1,032
$C^{\frac{1}{2}}$	23.7	25.5	32.1
h-factor	15,000	25,000	5,000
Ratio	.60	1.0	.20
Ranking	2	1	3

The ranking presented above suggests that $BKNO_3$ is a more effective igniter material than BP and NC with BP being more effective than NC. These results reflect the influence of the liquid and solid species in the exhaust stream through the values of specific heat capacity and molecular weight. Although the effects of potentially oxidizer rich species are not currently included in the ranking, the correlation constant C_1 could be modified, as is done in nucleate boiling heat transfer, to predict higher values when oxidizer rich species are present.

3.0 CONCLUSIONS

A diagnostic test series to evaluate the ignition effectiveness of black powder (BP), boron potassium nitrate ($BKNO_3$), and IMR 4895 (NC) has been conducted using the IECD and NACO propellant. The general utility of the IECD to acquire basic ignition data with NACO propellant has been demonstrated. The test series conducted was able to rank the ignition effectiveness of the three igniter materials in the following order, from most effective to least effective:

1. $BKNO_3$
2. BP
3. NC

Analytical review of the data suggest that the ignition effectiveness of $BKNO_3$ igniter material may be attributed to the high mole fraction of liquid and solid phase materials which have higher thermal inertia (longer persistence time) than either BP or NC materials.

Further research to understand the ignition of NOSIH propellants by multiphase igniter mixtures is recommended, including tasks to evaluate:

1. Effects of igniter vent geometry
2. Effects of new ignition materials
3. Effects of new propellants

Additional igniter characterization tasks are recommended to define the phase state of the igniter materials at the vent exit using a revolving drum to capture the igniter jet. If successful, this task would provide a spatial and temporal characterization of the gaseous, liquid, and solid phase materials as a function of expansion ratio.

The IECD is capable (with modification) of providing quenched propellant grains for examination. A series of properly planned and conducted quenching tests would provide partially burned

grains which could be examined for surface pitting (by hot solids) and erosion (uneven wetting) to provide additional insight to the ignition event. Quenching tests conducted at various stages from ignition to near burnout would provide partially burned grains for documenting surface regression, perforation growth, etc. as a function of pressure and time. These data would be of unique value to the current gun codes.

APPENDIX A

IECD Igniter Test Data with NACO Propellant

LEGEND

BP	~	Black Powder
BKN	~	Boron Potassium Nitrate
NC	~	IMR 4895
AV	~	Axial Vent
4080AV	~	4-.080 dia. axial vents, plus centerline 0.318 dia. axial vent
P	~	Number of pellets
No, Yes	~	NACO ignition

Appendix A - IECD Igniter Test Data with NACO Propellant

Test	Igniter Config	Mass	Bed l_1 (in)	NACO	Comments
IPT-001	BP-AV	2g	1.5	12P-NO	Axial Vent (.118ID) only.
-002	BP-AV	2g	.75	12P-NO	Reduced Inert Simulant Filter.
-003	BP-4080	2g	0	12P-NO	No Inert Simulant Filter.
-004	BP-4080	2g	0	12P-NO	
-005	BP-4080	2g	0	24P-YES	Missed Scope Event.
-006	BP-4080	2g	0	24P-NO	
-007	BP-4080	4g	0	24P-NO	Increased Igniter Mass to 4g.
-008	BP-4080AV	2g	0	24P-YES	Added Center Vent to Igniter. 10g of NACO. Ignition slow with dense visible exhaust gas coming from IECD.
-009	BP-4080AV	2g	0	48P-YES	20g of NACO. Ignition (NACO) better, but not crisp. Still volumes of visible gas coming from IECD after test.
-010	BP-4080AV	2g	0	96P-YES	40g of NACO. Ignition hard. P-t indicates approximately 5000 psi. Aft retainer failed. Recovered approximately 20g of unburned NACO. Note, that these grains are quenched at approximately 50%.
-011	BP-4080AV	2g	1.5	24g-NO	
-012	BP-4080AV	2g	0.75	24g-YES	Slow ignition with dense smoke. Missed event on scope.
-013	BP-4080AV	2g	0.75	24g-YES	Slow ignition, missed event.
-014	BP-4080AV	2g	0.75	24g-YES	Slow ignition. Peak pressure low.
-015	BP-4080AV	2g	0.75	30g-YES	Increased NACO charge. Better ignition. P-t pressure still low.

Test	Igniter Config	Mass	Bed l_1 (in)	NACO	Comments
IPT-016	BP-4080AV	2g	0.75	40g-YES	Good sharp ignition. Dense smoke not present, perhaps better combustion. Peak pressure good ∴ 40g of NACO looks good.
-017	NC-4080AV	1.41g	0.75	40g-YES	Igniter quiet, but good sharp NACO ignition. Peak pressure same as BP. Ignition delay same as BP.
-018	BKN-4080AV	0.91g	0.75	40g-YES	Igniter loud; good sharp NACO ignition. Peak pressure same as BP. Ignition delay much shorter than BP and NC. Will increase bed to see effects of additional inert simulant.
-019	BP-4080AV	2g	1.50	40g-YES	Good sharp ignition. Peak pressure slightly lower than tests with 0.75 inert l_1
-020	NC-4080AV	1.41g	1.50	40g-YES	Good ignition. Longer ignition delay than BP. Igniter quiet pop, not a bang.
-021	BKN-4080AV	0.91g	1.50	40g-YES	Loud igniter. Good NACO P-t; same maximum pressure as other 1.50 thickness shots. Ignition delay shorter than BP which is shorter than NC.
-022	BP-4080AV	2g	2.00	40g-NO	Good igniter, no NACO ignition. Ignition pulse on film.
-023	NC-4080AV	1.41g	2.00	40g-NO	Slight noise from ignition (typical). No NACO ignition. Some unburnt N.C. in l_1.

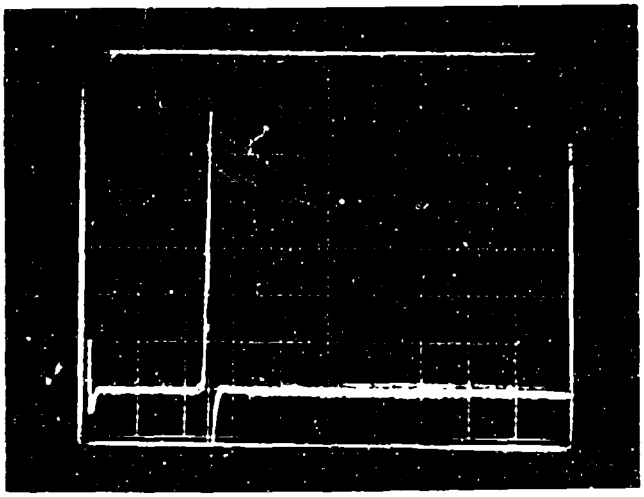
Test	Igniter Config	Mass	Bed l_1 (in)	NACO	Comments
IPT-024	BKN-4080AV	0.91g	2.00	40g-YES	All inert l_1 and l_3 seem to be fused together
-025	BKN-4080AV	0.91g	2.50	40g-YES	Possible extrusion into 5 vent holes
-026	BP-4080AV	1.61g	1.50	40g-YES	Possible blockage of vent holes (some inert melting).
-027	NC-4080AV	1.13	1.50	40g-NO	Ignition material found inside and outside of control element. Will repeat.
-028	NC-4080AV	1.13g	1.50	40g-NO	Same as above, poor NC ignition.
-029	BKN-4080AV	.73g	1.50	40g-YES	No sign of blockage vents.
-030	BP-4080AV	1.31g	1.50	40g-YES	Good clean ignition. Some delay in NACO ignition noticed (comparatively). Some sign of blockage.
-031	BKN-4080AV	0.60g	1.50	40g-YES	Typical
-032	BP-4080AV	1.02g	1.50	40g-YES	Typical
-033	BKN-4080AV	.46g	1.50	40g-YES	Typical
-034	BP-4080AV	.73g	1.50	40g-YES	Typical
-035	BKN-4080AV	.33g	1.50	40g-YES	Typical
-036	BP-4080AV	.43g	1.50	40g-NO	
-037	BKN-4080AV	0.20g	1.50	40g-NO	Soft primer noise.
-038	BP-4080AV	2.0g	1.50	40g-YES	
-039	BP-4080AV	2.0g	1.50	40g-YES	Possible blockage of vents.
-040	BP-4030AV	2.0g	1.50	40g-YES	
-041	NC-4080AV	1.41g	1.50	40g-YES	Double sound in beginning. Definite blockage of center vent, possible blockage of three others.

Test	Igniter Config	Mass	Be[illegible] L[illegible] ([illegible])	NACO	Comments
IPT-042	NC-4080AV	1.41g	1.50	40g-YES	Double venting sound in beginning.
-043	NC-4080AV	1.41g	1.50	40g-YES	Same double sound as beginning.
-044	BKN-4080AV	.91g	1.50	40g-YES	
-045	BKN-4080AV	.91g	1.50	40g-YES	Same blockage.
-046	BKN-4080AV	.91g	1.50	40g-YES	

APPENDIX B

IECO Igniter P-t Records with NACO Propellant

Pressure
500 psi/div

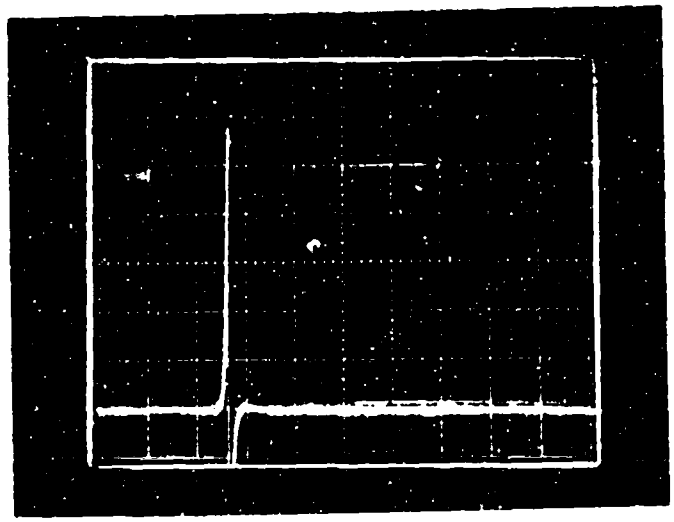


0.5 sec/div
Time

Test No.	16
Igniter Configuration	Axial Vent
Igniter Geometry	4080/1118
Igniter Material	Black Powder
Igniter Energy	1,368 calories
Propellant Material	NACO
Propellant Mass	40 grams
Zone #1 Thickness	0.75 in
Ignition Delay Time	1.17 sec.
Propellant P_{max}	2,953 psi

Pressure

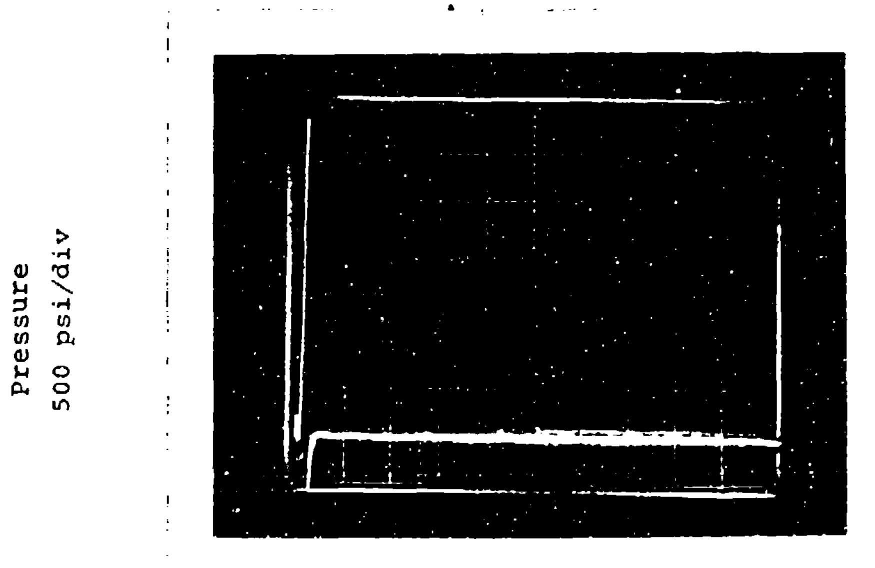
500 psi/div



0.5 sec/div

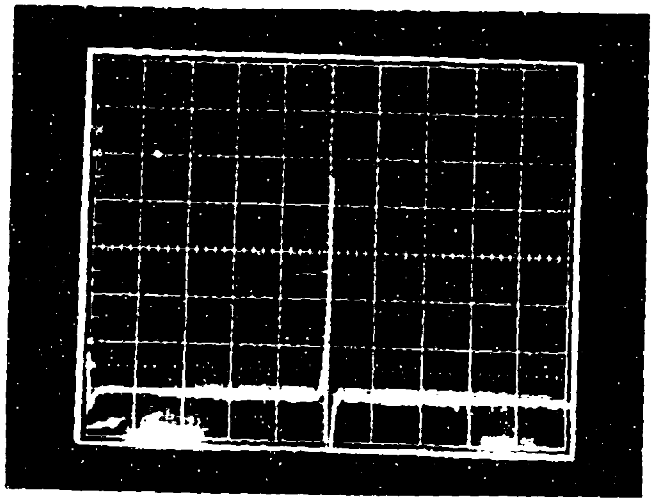
Time

Test No.	17
Igniter Configuration	Axial Vent
Igniter Geometry	4080/1118
Igniter Material	Nitrocellulose
Igniter Energy	1,368 calories
Propellant Material	NACO
Propellant Mass	40 grams
Zone #1 Thickness	0.75 in
Ignition Delay Time	1.21 sec.
Propellant P_{max}	2,934 psi



0.5 sec/div
Time

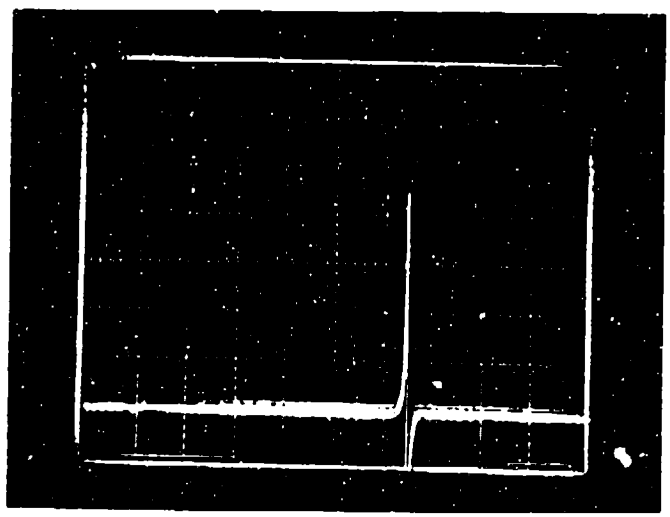
Test No.	18
Igniter Configuration	Axial Vent
Igniter Geometry	4080/1118
Igniter Material	$BKNO_3$
Igniter Energy	1,368 calories
Propellant Material	NACO
Propellant Mass	40 grams
Zone #1 Thickness	0.75 in
Ignition Delay Time	0.024 sec.
Propellant P_{max}	3,377 psi



Pressure
500 psi/div

0.5 sec/div
Time

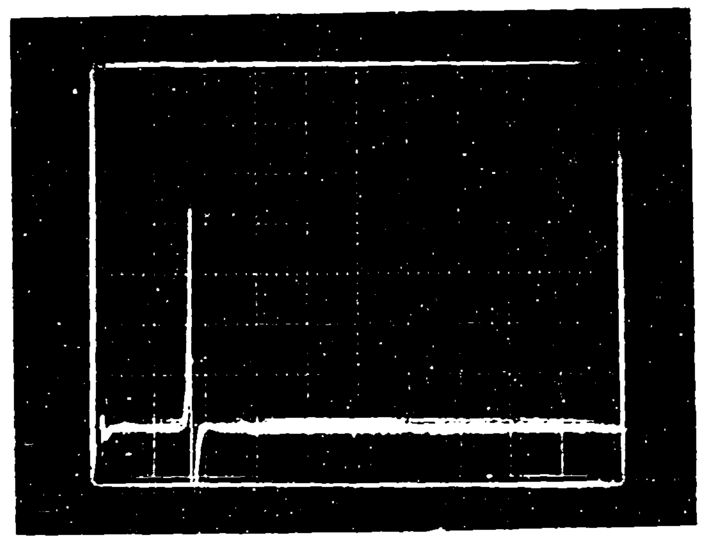
Test No.	19
Igniter Configuration	Axial Vent
Igniter Geometry	4080/1118
Igniter Material	Black Powder
Igniter Energy	1,368 calories
Propellant Material	NACO
Propellant Mass	40 grams
Zone #1 Thickness	1.50 in
Ignition Delay Time	2.45 sec.
Propellant P_{max}	2,332 psi



0.5 sec/div
Time

Test No.	20
Igniter Configuration	Axial Vent
Igniter Geometry	4080/1118
Igniter Material	Nitrocellulose
Igniter Energy	1,368 cal.
Propellant Material	NACO
Propellant Mass	40 grams
Zone #1 Thickness	1.50 in
Ignition Delay Time	3.16 sec.
Propellant P_{max}	2,326 psi

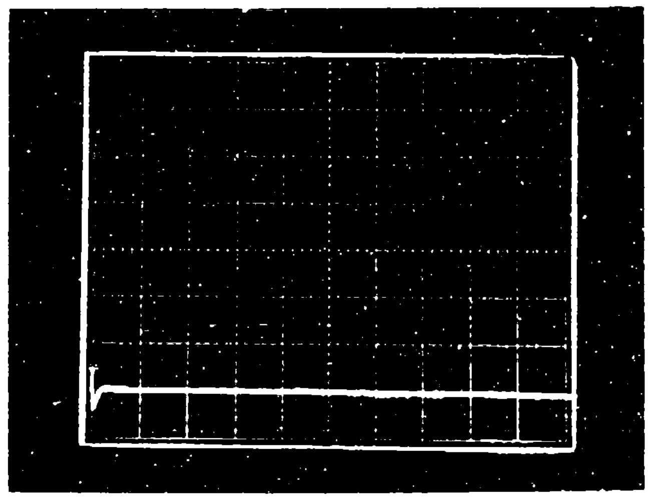
Pressure
500 psi/div



0.5 sec/div
Time

Test No.	21
Igniter Configuration	Axial Vent
Igniter Geometry	4080/1118
Igniter Material	$BKNO_3$
Igniter Energy	1,368 calories
Propellant Material	NACO
Propellant Mass	40 grams
Zone #1 Thickness	1.50 in
Ignition Delay Time	0.80 sec.
Propellant P_{max}	2,190 psi

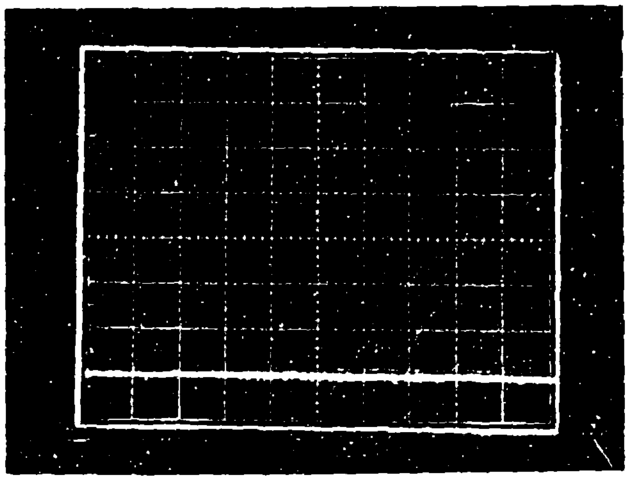
Pressure
500 psi/div



0.5 sec/div
Time

Test No.	22
Igniter Configuration	Axial Vent
Igniter Geometry	4080/1118
Igniter Material	Black Powder
Igniter Energy	1,368 calories
Propellant Material	NACO
Propellant Mass	40 grams
Zone #1 Thickness	2.00 in
Ignition Delay Time	Upper Energy Boundary
Propellant P_{max}	N/A

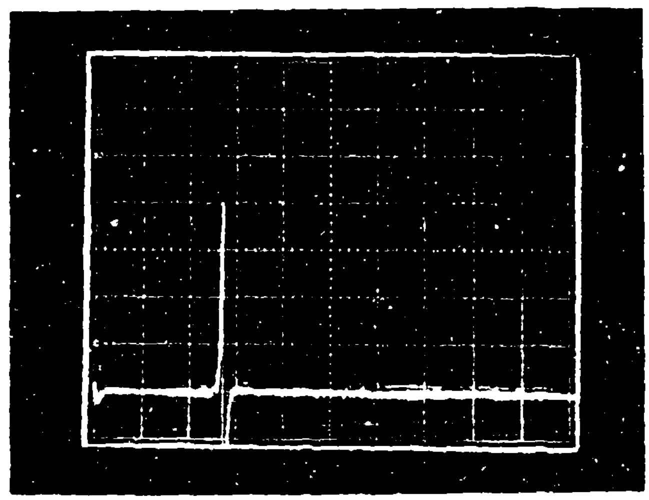
Pressure
500 psi/div



0.5 sec/div
Time

Test No.	23
Igniter Configuration	Axial Vent
Igniter Geometry	4080/1118
Igniter Material	Nitrocellulose
Igniter Energy	1,368 calories
Propellant Material	NACO
Propellant Mass	40 grams
Zone #1 Thickness	2.00 in
Ignition Delay Time	Upper Energy Boundary
Propellant P_{max}	N/A

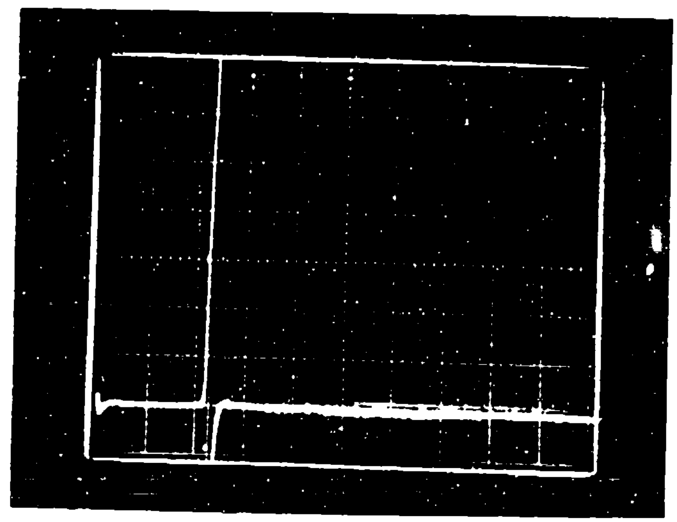
Pressure
500 psi/div



0.5 sec/div
Time

Test No.	24
Igniter Configuration	Axial Vent
Igniter Geometry	4080/1118
Igniter Material	$BKNO_3$
Igniter Energy	1,368 calories
Propellant Material	NACO
Propellant Mass	40 grams
Zone #1 Thickness	2.00 in
Ignition Delay Time	1.30 sec.
Propellant P_{max}	2,067 psi

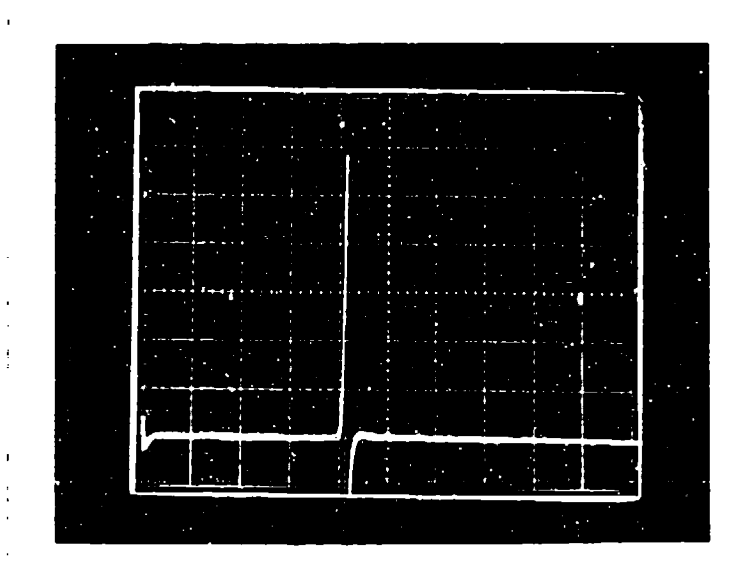
Pressure
500 psi/div



0.5 sec/div
Time

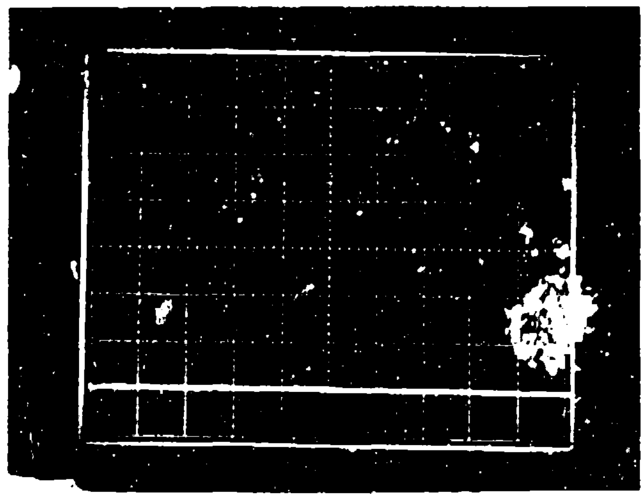
Test No.	25
Igniter Configuration	Axial Vent
Igniter Geometry	4080/1118
Igniter Material	$BKNO_3$
Igniter Energy	1,368 calories
Propellant Material	NACO
Propellant Mass	40 grams
Zone #1 Thickness	2.50 in
Ignition Delay Time	1.08 sec.
Propellant P_{max}	>3,500 psi

Pressure
500 psi/div



0.5 sec/div
Time

Test No.	26
Igniter Configuration	Axial Vent
Igniter Geometry	4080/1118
Igniter Material	Black Powder
Igniter Energy	1,100 calories
Propellant Material	NACO
Propellant Mass	40 grams
Zone #1 Thickness	1.50 in
Ignition Delay Time	2.00 sec.
Propellant P_{max}	2,897 psi

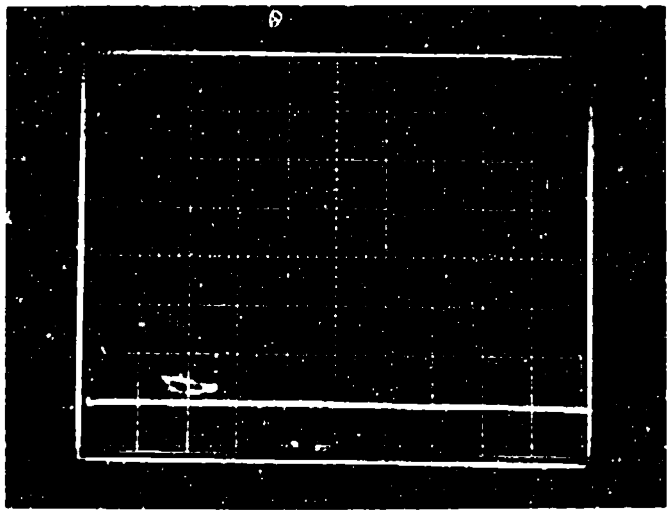


Pressure
500 psi/div

0.5 sec/div
Time

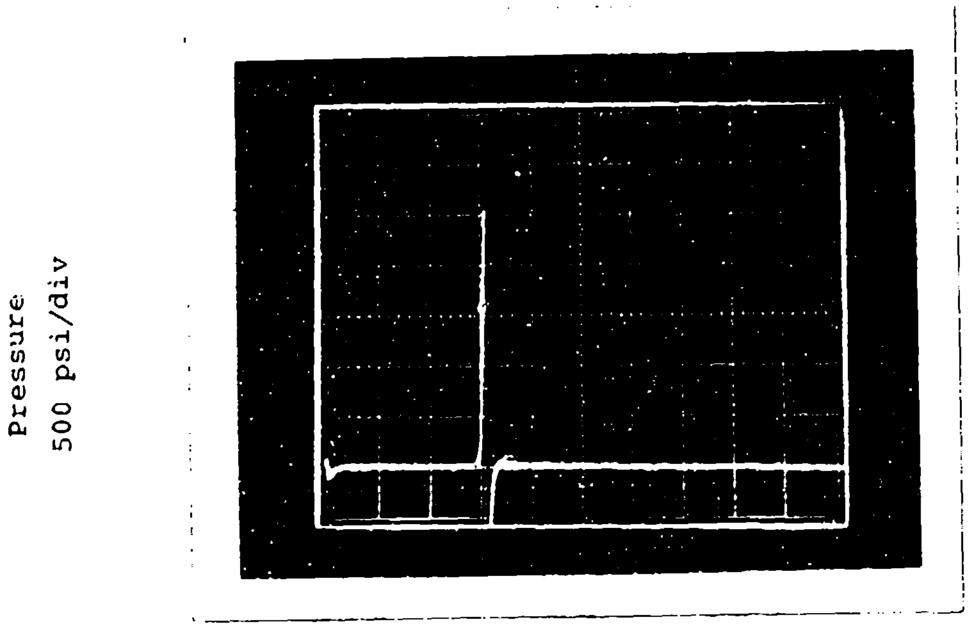
Test No.	27
Igniter Configuration	Axial Vent
Igniter Geometry	4080/1115
Igniter Material	Nitrocellulose
Igniter Energy	1,100 calories
Propellant Material	NACO
Propellant Mass	40 grams
Zone #1 Thickness	1.50 in
Ignition Delay Time	Lower Energy Boundary
Propellant P_{max}	N/A

Pressure
500 psi/div



0.5 sec/div
Time

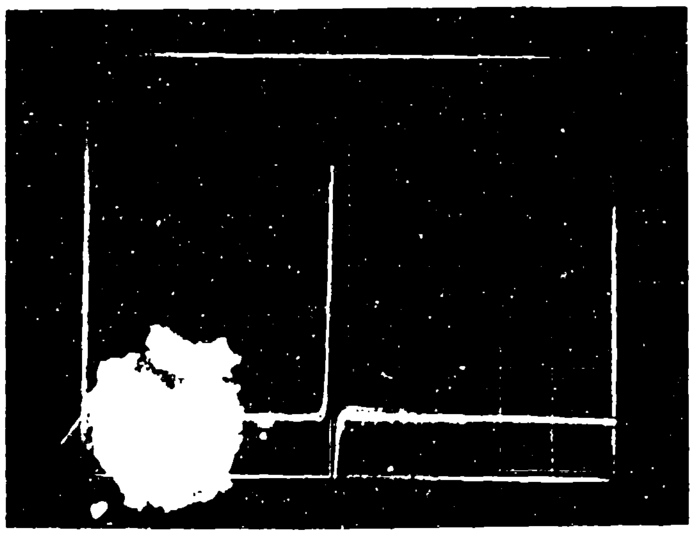
Test No.	28
Igniter Configuration	Axial Vent
Igniter Geometry	4080/1118
Igniter Material	Nitrocellulose
Igniter Energy	1,100 calories
Propellant Material	NACO
Propellant Mass	40 grams
Zone #1 Thickness	1.50 in
Ignition Delay Time	Lower Energy Boundary
Propellant P_{max}	N/A



0.5 sec/div

Time

Test No.	29
Igniter Configuration	Axial Vent
Igniter Geometry	4080/1118
Igniter Material	$BKNO_3$
Igniter Energy	1,100 calories
Propellant Material	NACO
Propellant Mass	40 grams
Zone #1 Thickness	1.50 in
Ignition Delay Time	1.47 sec.
Propellant P_{max}	2,560 psi

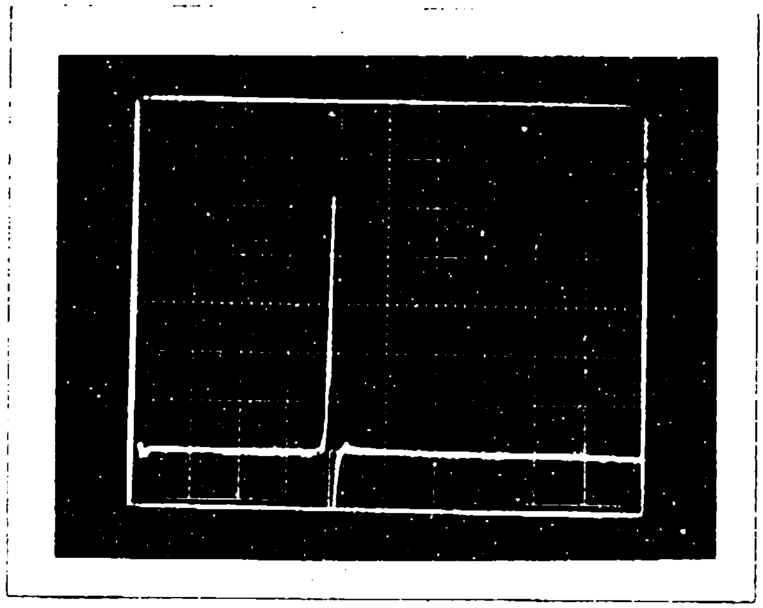


Pressure
500 psi/div

0.5 sec/div
Time

Test No.	30
Igniter Configuration	Axial Vent
Igniter Geometry	4080/1118
Igniter Material	Black Powder
Igniter Energy	900 calories
Propellant Material	NACO
Propellant Mass	40 grams
Zone #1 Thickness	1.50 in
Ignition Delay Time	2.27 sec.
Propellant P_{max}	2,491 psi

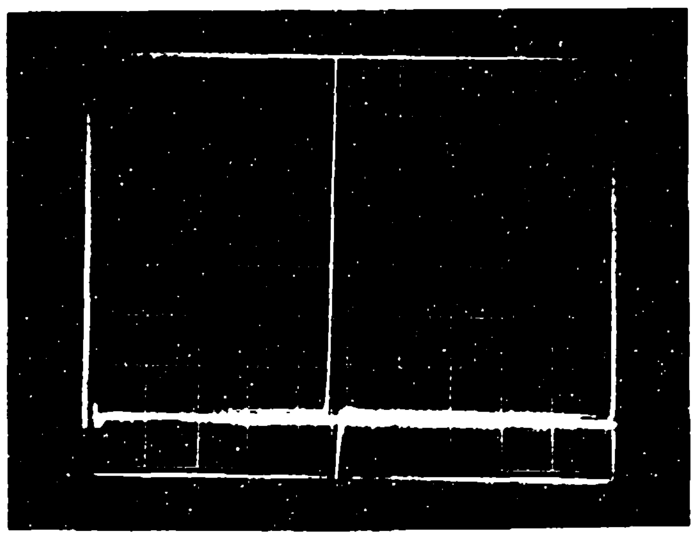
Pressure
500 psi/div



0.5 sec/div
Time

Test No.	31
Igniter Configuration	Axial Vent
Igniter Geometry	4080/1118
Igniter Material	$BKNO_3$
Igniter Energy	900 calories
Propellant Material	NACO
Propellant Mass	40 grams
Zone #1 Thickness	1.50 in
Ignition Delay Time	1.83 sec.
Propellant P_{max}	2,630 psi

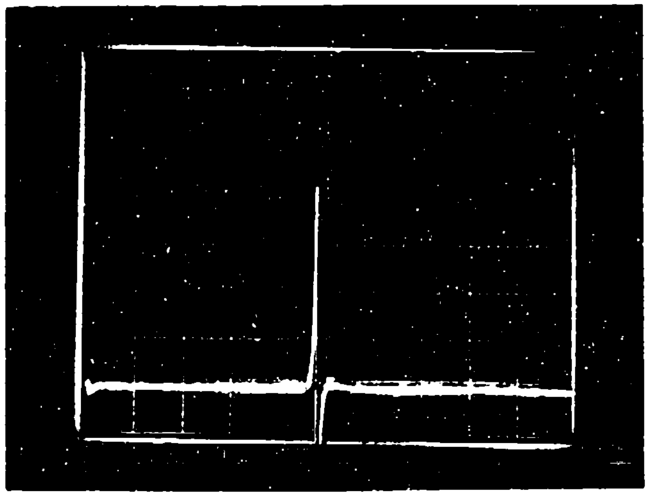
Pressure
500 psi/div



0.5 sec/div
Time

Test No.	32
Igniter Configuration	Axial Vent
Igniter Geometry	4080/1118
Igniter Material	Black Powder
Igniter Energy	700 calories
Propellant Material	NACO
Propellant Mass	40 grams
Zone #1 Thickness	1.50 in
Ignition Delay Time	2.30 sec.
Propellant P_{max}	>3,500 psi

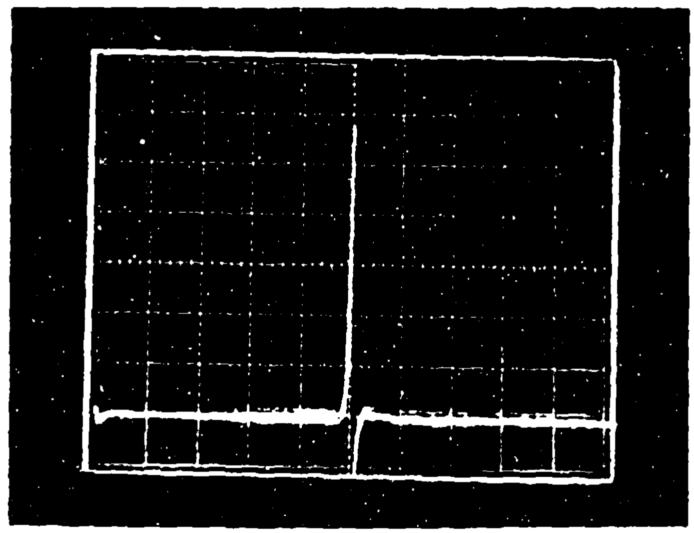
Pressure
500 psi/div



0.5 sec/div
Time

Test No.	33
Igniter Configuration	Axial Vent
Igniter Geometry	4080/1118
Igniter Material	$BKNO_3$
Igniter Energy	700 calories
Propellant Material	NACO
Propellant Mass	40 grams
Zone #1 Thickness	1.50 in
Ignition Delay Time	2.31 sec.
Propellant P_{max}	2,147 psi

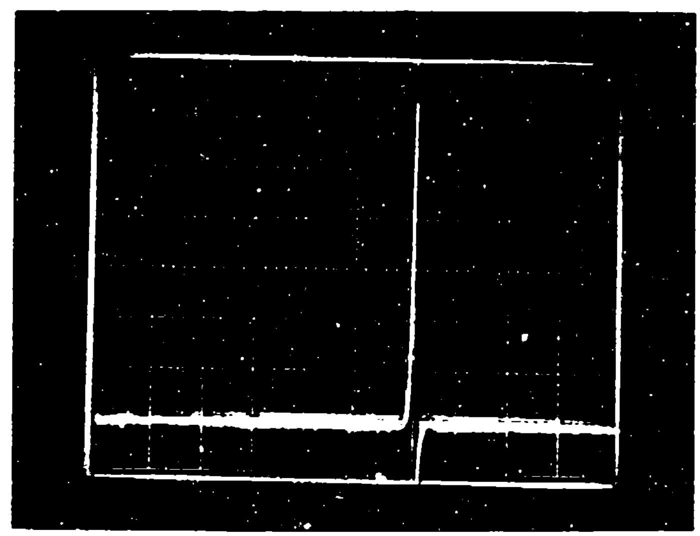
Pressure
500 psi/div



0.5 sec/div
Time

Test No.	34
Igniter Configuration	Axial Vent
Igniter Geometry	4080/1118
Igniter Material	Black Powder
Igniter Energy	500 calories
Propellant Material	NACO
Propellant Mass	40 grams
Zone #1 Thickness	1.50 in
Ignition Delay Time	2.41 sec.
Propellant P_{max}	2,896 psi

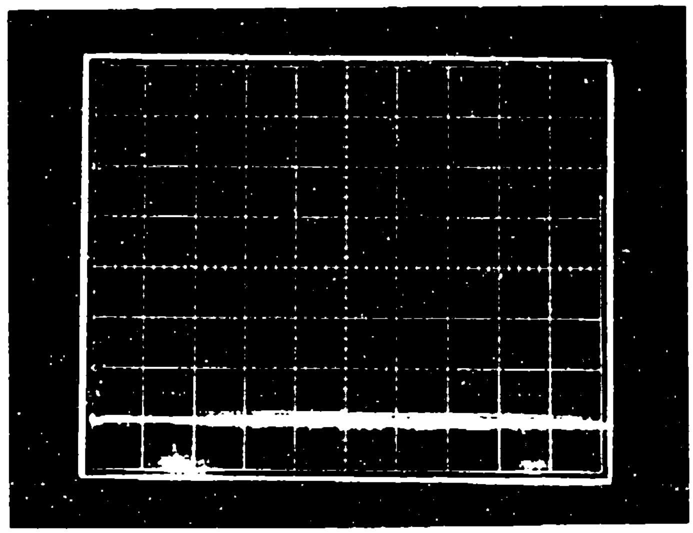
Pressure
500 psi/div



0.5 sec/div
Time

Test No.	35
Igniter Configuration	Axial Vent
Igniter Geometry	4080/1118
Igniter Material	$BKNO_3$
Igniter Energy	500 calories
Propellant Material	NACO
Propellant Mass	40 grams
Zone #1 Thickness	1.50 in
Ignition Delay Time	3.00 sec.
Propellant P_{max}	3,202 psi

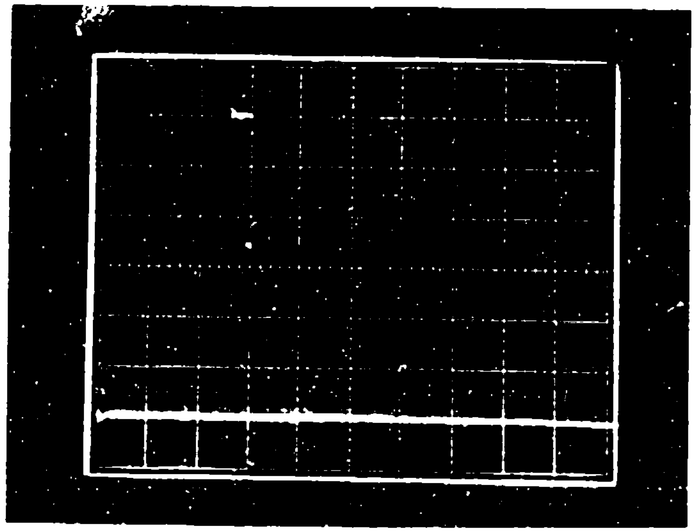
Pressure
500 psi/div



0.5 sec/div
Time

Test No.	36
Igniter Configuration	Axial Vent
Igniter Geometry	4080/1118
Igniter Material	Black Powder
Igniter Energy	300 calories
Propellant Material	NACO
Propellant Mass	40 grams
Zone #1 Thickness	1.50 in
Ignition Delay Time	Lower Energy Boundary
Propellant P_{max}	N/A

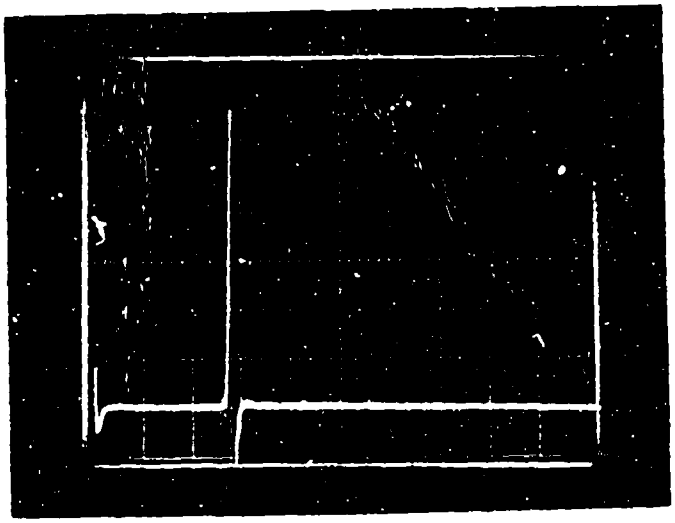
Pressure
500 psi/div



0.5 sec/div
Time

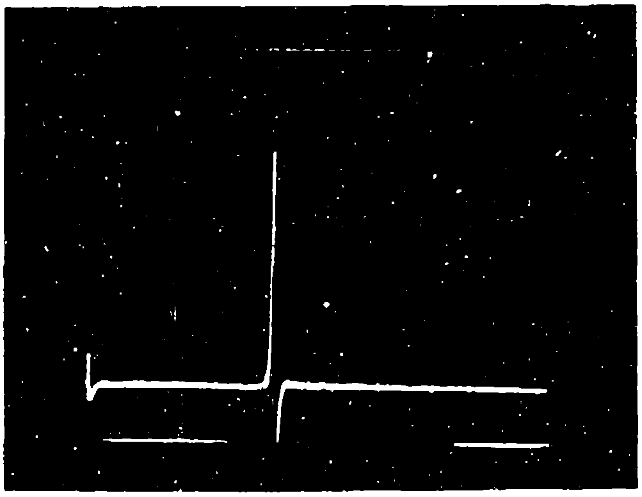
Test No.	37
Igniter Configuration	Axial Vent
Igniter Geometry	4080/1118
Igniter Material	$BKNO_3$
Igniter Energy	300 calories
Propellant Material	NACO
Propellant Mass	40 grams
Zone #1 Thickness	1.50 in
Ignition Delay Time	Lower Energy Boundary
Propellant P_{max}	N/A

Pressure
500 psi/div



0.5 sec/div
Time

Test No.	38
Igniter Configuration	Axial Vent
Igniter Geometry	4080/1118
Igniter Material	Black Powder
Igniter Energy	1,368 calories
Propellant Material	NACO
Propellant Mass	40 grams
Zone #1 Thickness	1.50 in
Ignition Delay Time	1.33 sec.
Propellant P_{max}	3,053 psi

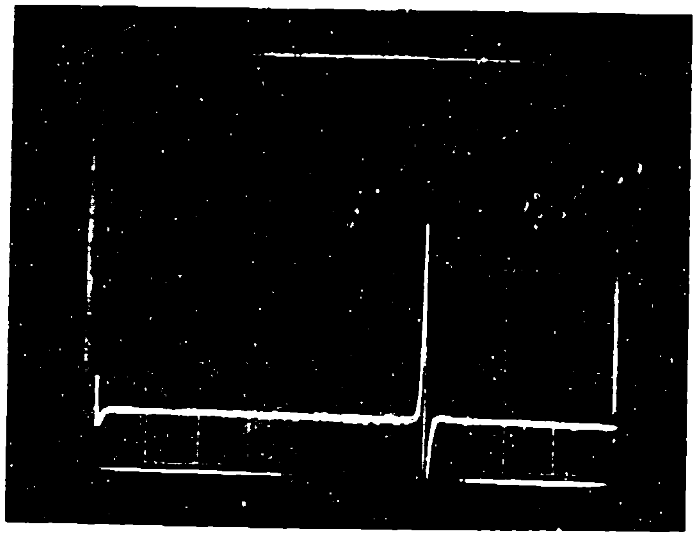


Pressure
500 psi/div

0.5 sec/div
Time

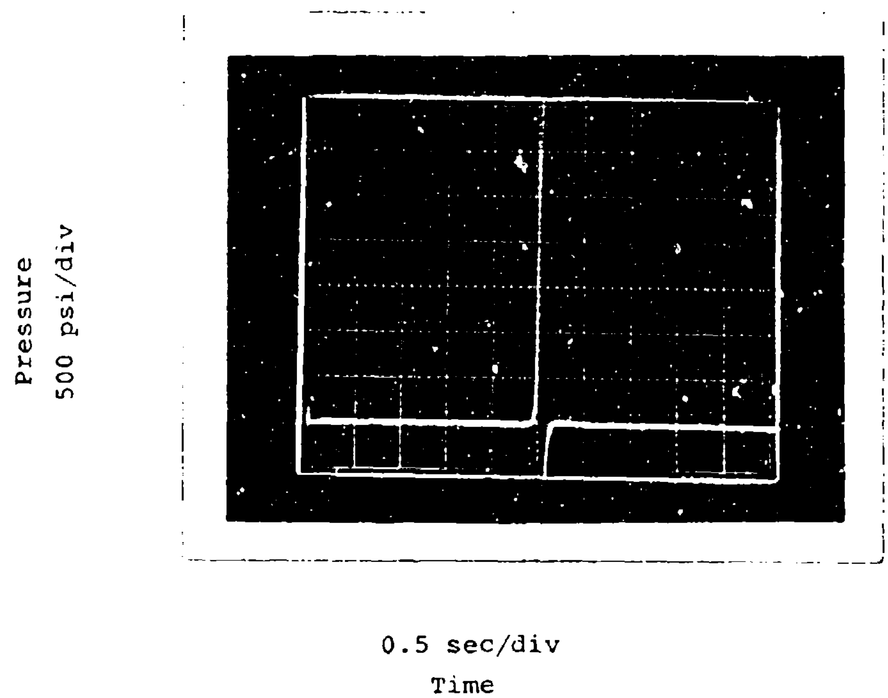
Test No.	39
Igniter Configuration	Axial Vent
Igniter Geometry	4080/1118
Igniter Material	Black Powder
Igniter Energy	1,368 calories
Propellant Material	NACO
Propellant Mass	40 grams
Zone #1 Thickness	1.50 in
Ignition Delay Time	1.87 sec.
Propellant P_{max}	2,553 psi

Pressure
500 psi/div



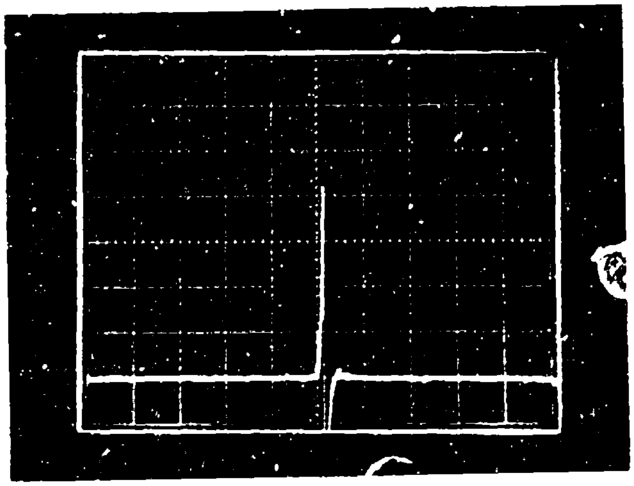
0.5 sec/div
Time

Test No.	40
Igniter Configuration	Axial Vent
Igniter Geometry	4080/1118
Igniter Material	Black Powder
Igniter Energy	1,368 calories
Propellant Material	NACO
Propellant Mass	40 grams
Zone #1 Thickness	1.50 in
Ignition Delay Time	3.10 sec.
Propellant P_{max}	1,964 psi



Test No.	41
Igniter Configuration	Axial Vent
Igniter Geometry	4080/1118
Igniter Material	Nitrocellulose
Igniter Energy	1,368 calories
Propellant Material	NACO
Propellant Mass	40 grams
Zone #1 Thickness	1.50 in
Ignition Delay Time	2.41 sec.
Propellant P_{max}	>3,500 psi

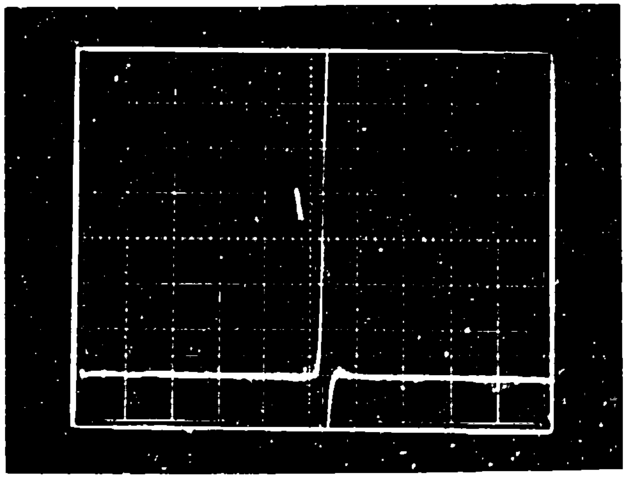
Pressure
500 psi/div



0.5 sec/div
Time

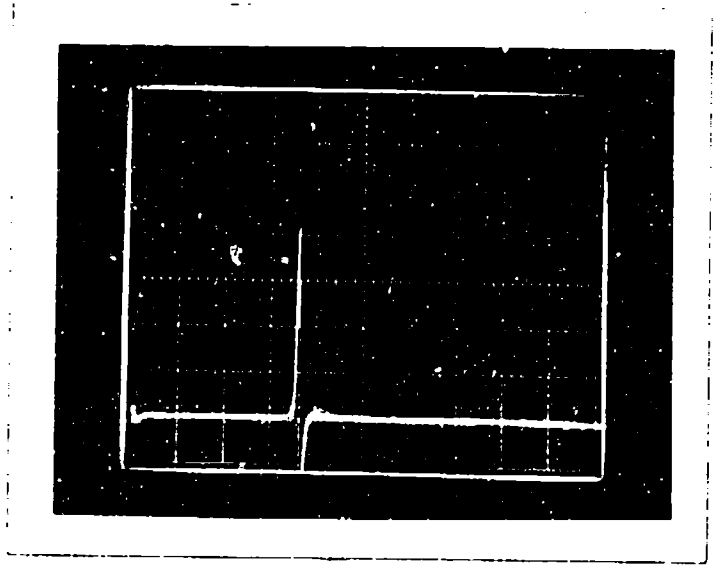
Test No.	42
Igniter Configuration	Axial Vent
Igniter Geometry	4080/1118
Igniter Material	Nitrocellulose
Igniter Energy	1,368 calories
Propellant Material	NACO
Propellant Mass	40 grams
Zone #1 Thickness	1.50 in
Ignition Delay Time	2.48 sec.
Propellant P_{max}	2,160 psi

Pressure
500 psi/div



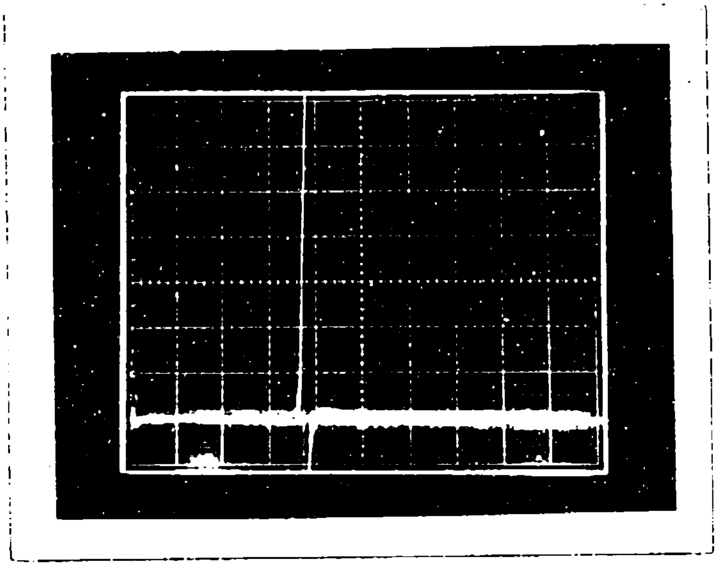
0.5 sec/div
Time

Test No.	43
Igniter Configuration	Axial Vent
Igniter Geometry	4080/1118
Igniter Material	Nitrocellulose
Igniter Energy	1,368 calories
Propellant Material	NACO
Propellant Mass	40 grams
Zone #1 Thickness	1.50 in
Ignition Delay Time	2.58 sec.
Propellant P_{max}	>3,500 psi

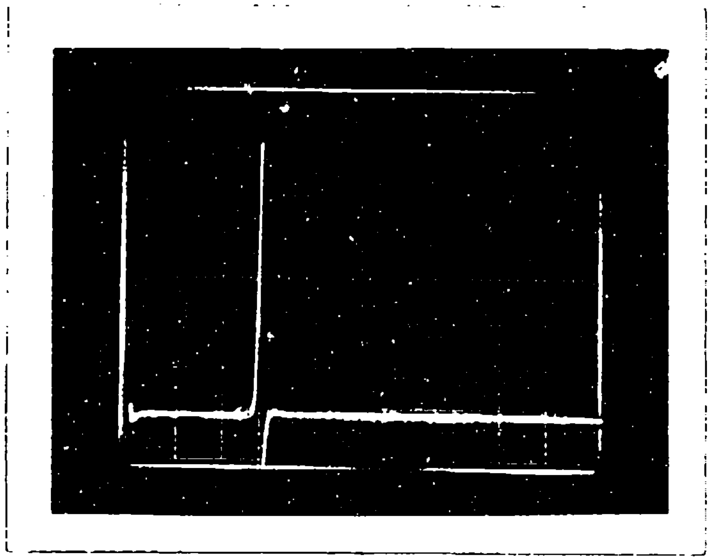


0.5 sec/div
Time

Test No.	44
Igniter Configuration	Axial Vent
Igniter Geometry	4080/1118
Igniter Material	$BKNO_3$
Igniter Energy	1,368 calories
Propellant Material	NACO
Propellant Mass	40 grams
Zone #1 Thickness	1.50 in
Ignition Delay Time	1.71 sec.
Propellant P_{max}	2,083 psi



Test No.	45
Igniter Configuration	Axial Vent
Igniter Geometry	4080/1118
Igniter Material	$BKNO_3$
Igniter Energy	1,368 calories
Propellant Material	NACO
Propellant Mass	40 grams
Zone #1 Thickness	1.50 in
Ignition Delay Time	1.78 sec.
Propellant P_{max}	>3,500 psi



Test No.	46
Igniter Configuration	Axial Vent
Igniter Geometry	4080/1118
Igniter Material	$BKNO_3$
Igniter Energy	1,368 calories
Propellant Material	NACO
Propellant Mass	40 grams
Zone #1 Thickness	1.50 in
Ignition Delay Time	1.32 sec.
Propellant P_{max}	2,991 psi

APPENDIX C

Ancillary Experimental Apparatus

APPENDIX C - Ancillary Experimental Apparatus

The ignition system, required for initiation of the electric M52A3B1 primer used with the IECD is a 120 VAC power source, supplied by local utility company connected to a constant voltage transformer which has an output of 120 VAC ±1/2%. This regulated voltage is the input voltage for a specific application power supply whose output voltage was designed to meet the electrical sensitivity specified by Olin Corporation, manufacturers of the electric M52A3B1 primer per attached drawings:

1. Application Power Supply, and
2. Electric M52A3B1-FA-874 Assembled Primer.

Data acquisition for the IECD utilizes the same utility supplied power source connected to a constant voltage transformer. This regulated output voltage is used in the signal generating portion and also the signal recording portion of the data acquisition system. The signal generating portion of this system is accomplished with equipment obtained from PCB Piezotronics, Inc. Product specifications and description are included in this appendix. The signal recording portion of the data acquisition system uses equipment obtained from Tektronics, Inc. Particular product information is also included in this appendix.

DO NOT SCALE THIS DRAWING, WORK TO FIGURES

REVISIONS				
SYM	DESCRIPTION	BY	DATE	APPROVED
	E.C.O. 7939			

M. M52A3B1-FA874 ELECTRIC PRIMER
(Equiv. to Gov't. Dwg. D7548066)

MIXTURE: FA 874

CHARGE: 2.35 - 3.00 Grains

RESISTANCE: 1,000-1,200,000 ohms.

IGNITION TIME: .300 Milliseconds Max.

ELECTRICAL SENSITIVITY: 100% firing using 10 microsecond discharge of a two microfarad capacitor charged to 160 volts.

STABILITY: Will withstand 85% R.H. 115°F. storage or 160°F dry storage, at least one year. Will withstand 250°F. for one hour.

SPECIFICATION: MIL-STD-1168 (latest revision) applies for lot numbering.

QUALITY CERTIFICATION: Upon request, can be furnished as follows: (Reference MIL-P-1394E)

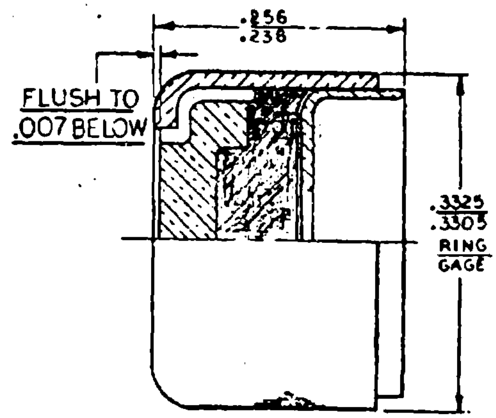
Dimensional:

Components: Vendors certification of compliance to applicable specification and drawings for cups, buttons and cup-supports are retained in Olin files.

Primer: AQL 2.50% (cumulative).

Visual: 100% examination of each lot to remove visual defects listed in Paragraph 4.4.3.4 of Military Specification MIL-P-1394E

Tests: Tests listed in Table II of MIL-P-1394E will be performed. Each test will comply with the applicable requirement.



METAL PARTS: Copper Alloys

INSULATOR: Blue Vinylite

PRIMER FOIL: White Kraft paper, coated

APPROVALS	DATE
AMMUNITION MANUFACTURING: K. J. Thaller for C. A. Holler	11/2/77
MANUFACTURING ENGINEERING: [signature]	11/7/77
PRODUCT ENGINEERING: R. Van Wyk	11/7/77
AMMUNITION QUALITY ASSUR.: [signature]	11/7/77
ACQUISITION CONTRACT ADM: [signature]	11/8/77

TITLE: ELECTRIC M52A3B1 -FA-874 ASSEMBLED PRIMER

DRAWN BY: MCDONNELL DATE: 10-21-76

CHECKED: DATE:

SCALE:

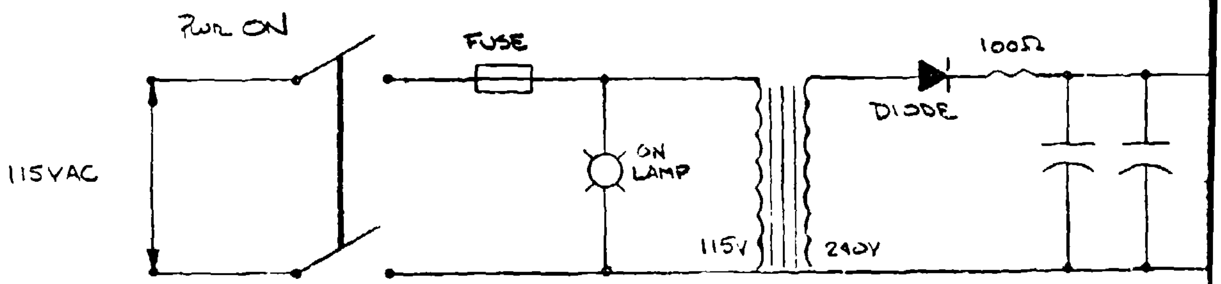
WINCHESTER-WESTERN DIVISION
Olin Corporation
Olin

DWG SIZE: DWG NO: P-7217-26

SHEET OF

AF 12245A

DWG.



POWER SUPPLY

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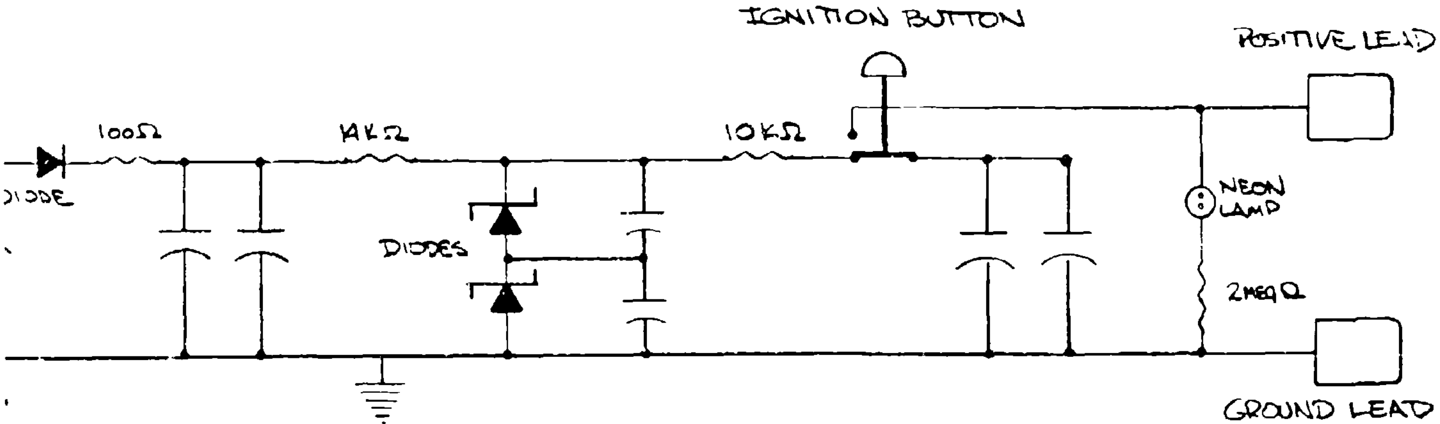
DWG. NO	SH	REV

REVISIONS			
REV	DESCRIPTION	DATE	APPROVED



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TOLERANCES:
FRACTIONS ±
3 PLACE DECIMALS ±
2 PLACE DECIMALS ±
MATERIAL

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DRAWN

ISSUED

Applied Combustion Technology Inc
29 Coburn Ave. • Orlando, FL 32805
A Subsidiary of Mechtron International Corporation

POWER SUPPLY, I.E.C.D

SIZE	FSCM NO.	DWG. NO.	REV
B		7710002	

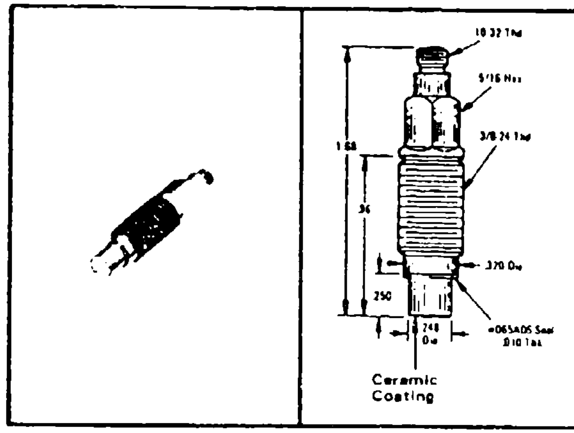
SCALE		SHEET

QUARTZ, LOW-IMPEDANCE, VOLTAGE-MODE

HIGH-PRESSURE TRANSDUCER

with built-in amplifier **Model 109A**

PCB PIEZOTRONICS



- range to 100,000 psi
- acceleration-compensated quartz element
- high resonant frequency: 500,000 Hz
- frequency-tailored — nearly non-resonant response
- high-level (10V), low-impedance output
- static calibration

For shock wave, blast, explosion, detonation and ballistic applications, in shock and vibration environments. Not suited for continuous hydraulic nor rapid-fire ammunition testing.

Model 109A is a high-pressure quartz transducer with a built-in unity-gain amplifier for dynamic and short term static pressure measurements to 100,000 psi on shock tubes, detonation chambers, closed bombs, gas guns and explosive metal forming machines. To improve the quality of the signal, an internal compensating accelerometer reduces vibration sensitivity and suppresses resonance effects, which tend to mask the actual pressure signal. An integral diaphragm with a permanent ceramic coating insulates and protects the transducer against damaging temperature effects.

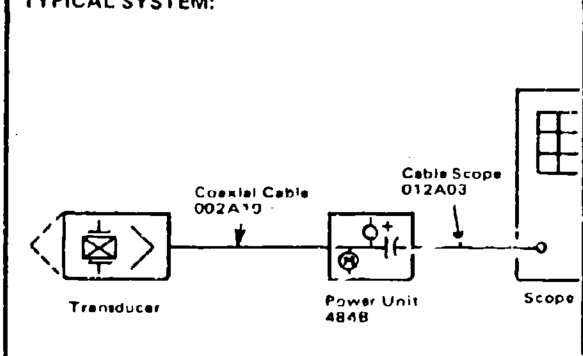
The Model 109A installs flush or recessed directly in the test object and fits many existing ports for older type transducers. The thin shoulder seal illustrated is recommended for new installations. Request a detailed installation drawing.

When connected to a PCB power unit, self-amplifying transducers generate a high-level low-impedance analog output signal proportional to the measurand and compatible with most readout instruments. The simple power unit circuit powers the transducer over the signal lead (coaxial or 2-wire), eliminates bias on the output and monitors normal or faulty operation. Signal quality is almost independent of cable length, condition and motion.

Model 109A excells in tough applications. If detonation, stress waves, shock, strain, motion or temperature is involved or causing trouble (noisy signals), try this rugged, sophisticated instrument. The thermal, motion and resonance compensating techniques employed within have helped improve the quality of the result in numerous difficult situations.

SPECIFICATIONS: Model No.		109A
Range (8 volt output)	psi	80,000
Overrange (10 volt output)	psi	100,000
Resolution	psi	2
Sensitivity	mV/psi	0.1
Resonant Frequency	Hz	500,000
Rise Time	μsec	1
Discharge Time Constant	sec	2000
Low Frequency (−5%)	Hz	0.0003
Linearity (B.S.L., Zero Based)	%	2
Output Impedance	ohms	100
Excitation (thru C.C. Diode)	VDC/MA	+18 to 24/2 to 20
Acceleration Sensitivity	psi/g	0.004
Temperature Coefficient	%/°F	0.03
Temperature Range	°F	−100 to +275
Shock	g	200/20,000
MODEL NO. (Optional Versions) Range to 120,000 psi		**109A02**
Conventional Charge-Mode No. (Sensitivity 0.25 pC/psi; for charge amplifiers)		**119A**

TYPICAL SYSTEM:



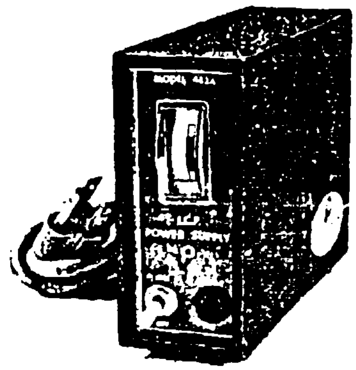
A. C. MODE, BASIC

LINE POWER UNIT

for voltage-mode transducers **Model 482A**

PCB PIEZOTRONICS

- powers transducers with built-in or attached amplifiers
- supplies power over signal lead
- eliminates bias on output
- monitors normal or faulty system operation
- provides adjustable constant-current excitation



For powering low-impedance piezoelectric transducers with built-in or attached amplifiers and coupling them to versatile readout instruments; and especially for driving long transducer cables.

Model 482A Line Power Unit powers the transducer over the signal lead and couples self-amplifying PCB transdcuers to oscilloscopes, recorders or other readout instruments. In the coupling process, it eliminates D.C. power bias from the output by means of a coupling capacitor. It also monitors normal operation of the system with a meter that detects such faults as cable and connector open or short circuits and transducer amplifier trouble. With a 24V D.C. regulator, Model 482A provides an output signal range linear to ± 10 volts. Constant current excitation adjustable from 2 to 20 mA (factory set at 12 mA) is supplied to transducer to improve linearity and cable driving capabilities. Higher magnitude supply currents drive longer cables and provide more available output current. With medium length cables, output current is generally available to within 2 mA of the supply current.

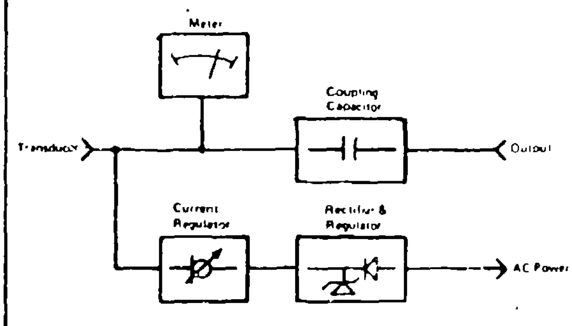
Like the transducer discharge circuit, the capacitive coupling circuit to the readout instrument also eliminates D.C. signal components at an exponential rate. When the readout load impedance is one megohm or more, the coupling time constant exceeds 10 seconds, which is sufficiently long for most applications.

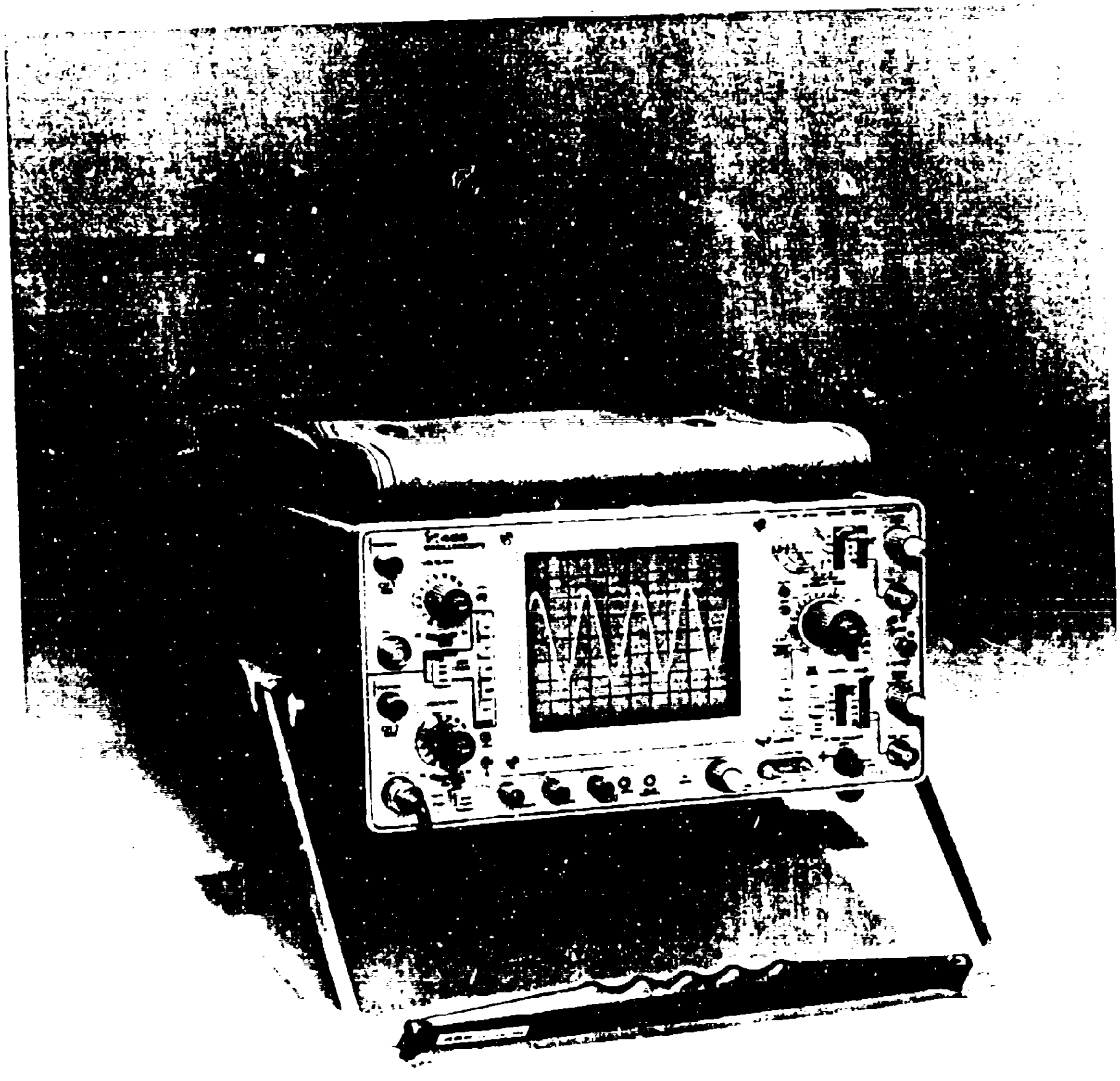
For static calibrating or other purposes, Model 482A can be operated in a D.C. mode by taking the output signal directly off the transducer lead through a "T" connector or by shorting across the internal coupling capacitor. The resulting 11V D.C. bias on the output lead can be eliminated, if necessary, by a series battery or floating D.C. supply.

SPECIFICATIONS: Model No.		482A
Transducer Excitation	VDC	+22
Excitation Current (adjustable)[1]	mA	2 to 20
Voltage Gain		1
Coupling Capacitor	μF	10
Output Signal, F.S.	± volts	10
Output Current	mA	to 10
Noise, Wideband (pk-pk max.)	μV	500
Size	in	1.8x4.3x6
Weight	lb	2
Transducer Connector	micro	10-32
Output Connector		BNC
Power Cord (3-wire)	ft	6
Power Required (60 Hz)	V/A	100-125/0.3
OPTIONAL MODELS:		
Four Channel Version		482A04
Fixed Constant - Current Supply (2mA Diode)		482A07
Three Position Gain Switch (X1, 10, 20) (with 4mA Constant-Current Supply)		482A10

NOTE: (1) Factory set at 4mA.
(2) Output Cable not supplied, Order Model 012A03

BLOCK DIAGRAM:





1661-19

Fig. 1-1. 465 Oscilloscope.

SPECIFICATIONS

Introduction

The 465 Oscilloscope is a wide-band, portable oscilloscope designed to operate in a wide range of environmental conditions. The instrument is light in weight and compact of design for ease of transportation, yet capable of performance necessary for accurate high-frequency measurements. The dual-channel dc-to-100 megahertz vertical deflection system provides calibrated deflection factors from 5 millivolts to 5 volts/division. The bandwidth limiting switch reduces interference from signals above about 20 megahertz for viewing low-frequency, low-level signals.

The trigger circuits provide stable sweep triggering to beyond the bandwidth of the vertical deflection system. Separate controls are provided to select the desired mode of triggering for the A and B sweeps. The A sweep can be operated in one of three modes: automatic triggering, normal triggering, or single sweep. A variable trigger holdoff control provides the ability for A sweep to trigger stably on aperiodic signals or complex digital words. The horizontal deflection system has calibrated sweep rates from 0.5 second to 0.05 microsecond/division. A X10 magnifier increases each sweep rate by a factor of 10 to provide a maximum sweep rate of 5 nanoseconds/division in the 0.05 μs position. The delayed and mixed sweep features allow the start of the B sweep to be delayed a selected amount from the start of A sweep to provide accurate relative-time measurements. Calibrated X-Y measurements can be made with Channel 2 providing the vertical deflection and Channel 1 providing the horizontal deflection (TIME/DIV switch fully counterclockwise and VERT MODE switch to CH 2). The regulated dc power supplies ensure that instrument performance is not affected by variations in line voltage and frequency. Maximum power consumption of the instrument is approximately 75 watts.

The following instrument specifications apply over an ambient temperature range of −15°C to +55°C unless otherwise specified. Warm-up time for specified accuracies is 20 minutes. The calibration procedure given in section 6, if performed completely, will allow an instrument to meet the electrical characteristics listed below.

VERTICAL DEFLECTION SYSTEM

Deflection Factor

Calibrated range is from 5 millivolts to 5 volts/division in 10 steps in a 1-2-5 sequence. Accuracy is within 3%. Uncalibrated VAR control provides deflection factors continuously variable between the calibrated settings and extends deflection factor to at least 12.5 volts/division in the 5 VOLTS/DIV position.

Frequency Response

Bandwidth in both Channel 1 and Channel 2 is dc to at least 100 megahertz from −15°C to +40°C and dc to at least 85 megahertz from +40°C to +55°C. Risetime is 3.5 nanoseconds or less from 0°C to +40°C and 4.2 nanoseconds or less from +40°C to +55°C. The ac-coupled lower −3 dB point is 10 hertz or less (1 hertz or less when using a 10X probe). Vertical system bandwidth with the BW LIMIT pushbutton pulled is approximately 20 megahertz.

Chopped Mode Repetition Rate

Approximately 250 kilohertz.

Input Resistance And Capacitance

One megohm within 2% paralleled by approximately 20 picofarads.

Maximum Input Voltage

Dc coupled: 250 V (dc + peak ac) or 500 V p-p ac at 1 kHz or less.

Ac coupled: 500 V (dc + peak ac) or 500 V p-p ac at 1 kHz or less.

Cascaded Operation (CH 1 VERT SIGNAL OUT Connected to CH 2 OR Y)

Bandwidth is dc to at least 50 MHz with a sensitivity of at least 1 millivolt/division.

TRIGGERING

Sensitivity

DC Coupled: 0.3 division internal or 50 millivolts external from dc to 25 megahertz, increasing to 1.5 divisions internal or 150 millivolts external at 100 megahertz.

AC Coupled: 0.3 division internal or 50 millivolts external from 60 hertz to 25 megahertz, increasing to 1.5 divisions internal or 150 millivolts external at 100 megahertz. Attenuates all signals below about 60 hertz.

LF REJ Coupled: 0.5 division internal or 100 millivolts external from 50 kilohertz to 25 megahertz, increasing to 1.5 divisions internal or 300 millivolts external at

100 megahertz. Blocks dc and attenuates all signals below about 50 kilohertz.

HF REJ Coupled: 0.5 division internal or 100 millivolts external from 60 hertz to 50 kilohertz. Blocks dc and attenuates all signals below about 60 hertz and above about 50 kilohertz.

Trigger Jitter

0.5 nanosecond or less at 5 nanoseconds/division with 100 megahertz applied (X10 MAG on).

External Trigger Input

Maximum input voltage is 250 volts (dc + peak ac) or 250 volts peak to peak ac (1 kilohertz or less). Input resistance is 1 megohm within 10%.

Level Range

EXT: At least + and − 2 volts, 4 volts peak to peak.

EXT ÷ 10: At least + and − 20 volts, 40 volts peak to peak.

HORIZONTAL DEFLECTION SYSTEM

Calibrated Sweep Range

A Sweep: From 0.5 second/division to 0.05 microsecond/division in 22 steps in a 1-2-5 sequence. X10 MAG extends maximum sweep rate to 5 nanoseconds/division.

B Sweep: From 50 milliseconds/division to 0.05 microsecond/division in 19 steps in a 1-2-5 sequence. X10 MAG extends maximum sweep rate to 5 nanoseconds/division.

Calibrated Sweep Accuracy

Unmagnified sweep accuracy is within 2% from +20°C to +30°C (+68°F to +86°F) and within 3% from −15°C to +20°C and +30°C to +55°C (+5°F to +68°F and +86°F to +131°F). For the same temperature ranges, magnified sweep accuracy is within 3% and within 4% respectively. Exclude the first and last 50 nanoseconds of the 5 nanoseconds, 10 nanoseconds, and 20 nanoseconds magnified sweep rates. Accuracy specifications apply over full 10 divisions unless otherwise specified.

Sweep accu[illegible] or less division portion of the sweep, is within 5%. Exclude the first and last magnified divisions of the 5 nanosecond and 10 nanosecond/division magnified sweep rates. Also exclude the first and last 50 nanoseconds of the 5, 10, and 20 nanoseconds/division sweep rates.

Mixed sweep accuracy is within 2% plus the measured A sweep error when viewing the A sweep portion only. The B sweep portion retains its normal accuracy. The following exclusion applies: First .5 division after display start, and first .2 division or 1 μs (whichever is greater) after transition of A to B.

A Time/Division Variable Range

Provides continuously variable (Uncalibrated) sweep rates between the calibrated settings of the A TIME/DIV switch. Extends the slowest A sweep rate to at least 1.25 seconds/division.

A Trigger Holdoff

Increases A sweep holdoff time by at least a factor of 10.

Delay Time And Differential Time Measurement Accuracy

	+10°C to +35°C (+50°F to +95°F)	−15°C to +55°C (+5°F to +131°F)
Over 1 Or More Major Dial Division	±1%	±2.5%
Over Less Than 1 Major Dial Division	±0.01 Major Dial Division	±0.03 Major Dial Division

Delay or Differential Time Jitter

Within 0.002% (less than one part in 50,000) of the maximum available delay time when operating on power line frequencies other than 50 hertz.

Within 0.005% (less than one part in 20,000) of the maximum available delay time when operating on 50 hertz power line frequency.

Maximum available delay time is 10 times the setting of the A TIME/DIV switch.

Calibrated Delay Time (A VAR set to calibrated position)

Continuous from 5 seconds to 0.2 microsecond.

X-Y OPERATION

Sensitivity

Same as vertical deflection system.

X Axis deflection accuracy within 4%.

Variable Range

Same as vertical deflection system.

X-Axis Bandwidth

Dc to at least 4 megahertz.

Y-Axis Bandwidth

Same as vertical deflection system

Input Resistance

Same as vertical deflection system.

Input Capacitance

Same as vertical deflection system

Maximum Usable Input Voltage

Same as vertical deflection system

CALIBRATOR

Output

An approximate 1 kilohertz, 30 milliampere (within 2%), 300 millivolt (within 1%), square-wave signal.

Z AXIS INPUT

Sensitivity

A 5-volt peak to peak signal causes noticeable modulation at normal intensity

Usable Frequency Range

From dc to 50 megahertz

SIGNAL OUTPUTS

Ch 1 Vertical

Output voltage is at least 50 millivolts/division into a 1 megohm load (at least 25 millivolts/division into a 50 ohm load)

Bandwidth is from dc to at least 50 megahertz into a 50 ohm load

Output dc level is approximately zero volts

A and B +Gate

Output voltage is approximately 5.5 volts, positive-going

POWER SOURCE

Line Voltages

110, 115, 120, 220, 230, or 240 Volts ac (all within 10%), depending on the settings of the Line Voltage Selector switch and the Regulating Range Selector assembly, with a line frequency of 48 to 440 hertz. Maximum power consumption is 75 watts at 115 volts ac, 60 hertz.

CATHODE-RAY TUBE (CRT)

Graticule Area

Eight by 10 centimeters.

Phosphor

P31 is the standard phosphor with P11 offered as an option.

SUPPLEMENTAL INFORMATION

NOTE

The following supplemental information represents limits that, when met, ensure optimum instrument operation. They are, however, not instrument specifications but are intended to be used only as maintenance or operational aids.

VERTICAL DEFLECTION SYSTEM

Low—Frequency Linearity

There should be no more than 0.1 division of compression or expansion of a 2-division signal, at center screen, when the signal is positioned to the upper and lower extremes of the crt graticule area.

Bandwidth Limiter Switch

The -3 dB point should be between 15 and 25 megahertz with the 20 MHz BW switch pulled (yellow showing)

Step Response Aberrations

Aberrations on a positive going 5 division step should be +3%, -3% or less not to exceed 3% peak-to-peak on

all ranges except at 5 VOLTS/DIV Aberrations at 5 VOLTS/DIV should be +4%, −4% or less not to exceed 4% peak-to-peak. Position effect should cause aberrations to be no more than +5%, −5% not to exceed 5% peak-to-peak.

Common-Mode Rejection Ratio (CMRR)

At least 10:1 at 20 megahertz for common mode signals of 6 divisions or less with vertical gain adjusted for best cmrr at 50 kilohertz.

Step Attenuator Balance

Adjustable to 0.2 division or less of trace shift when switching between adjacent deflection factors.

Trace Shift as Variable is Rotated

Adjustable to 1 division or less.

Invert Trace Shift

Two divisions or less when switching from normal to inverted.

Input Gate Current

0.5 nanoampere or less (0.1 division of deflection at 5 millivolts/division) from +20°C to +30°C. Four nanoamperes or less (0.8 division of deflection at 5 millivolts/division) from −15°C to +55°C.

Channel Isolation

At least 100:1 at 25 megahertz.

Position Range

Twelve divisions up and 12 divisions down from graticule center.

TRIGGERING

External Trigger Input Capacitance

Twenty picofarads within 30%.

HORIZONTAL DEFLECTION SYSTEM

A Sweep Length

10.5 to 11.5 divisions.

Magnifier Registration

There should be 0.2 division or less difference at graticule center when switching from MAG on to MAG off.

Position Range

Should be able to position the start of the sweep to the right of graticule center, and the end of the sweep to the left of graticule center.

Phase Difference Between X And Y Axes Amplifiers

Typically 3° or less from dc to 50 kilohertz.

CALIBRATOR

Repetition Rate

Repetition rate accuracy is 1 kilohertz within 25%.

Output Resistance

Approximately 9.4 ohms.

EXTERNAL Z AXIS INPUT

Voltages applied to the EXT Z AXIS INPUT connector should be limited to less than 100 volts (dc + peak ac) or 100 volts peak to peak ac at 1 kilohertz or less.

OUTPUT RESISTANCES

Output resistance of the CH 1 VERT SIG OUT connector is approximately 50 ohms.

Output resistance of A+ and B+ GATE outputs is approximately 500 ohms.

CATHODE-RAY TUBE

Resolution

Typically at least 15 lines/division horizontally and vertically.

Geometry

0.1 division or less of tilt or bowing.

Raster Distortion

0.1 division or less.

Nominal Accelerating Potential

Approximately 18,500 volts.

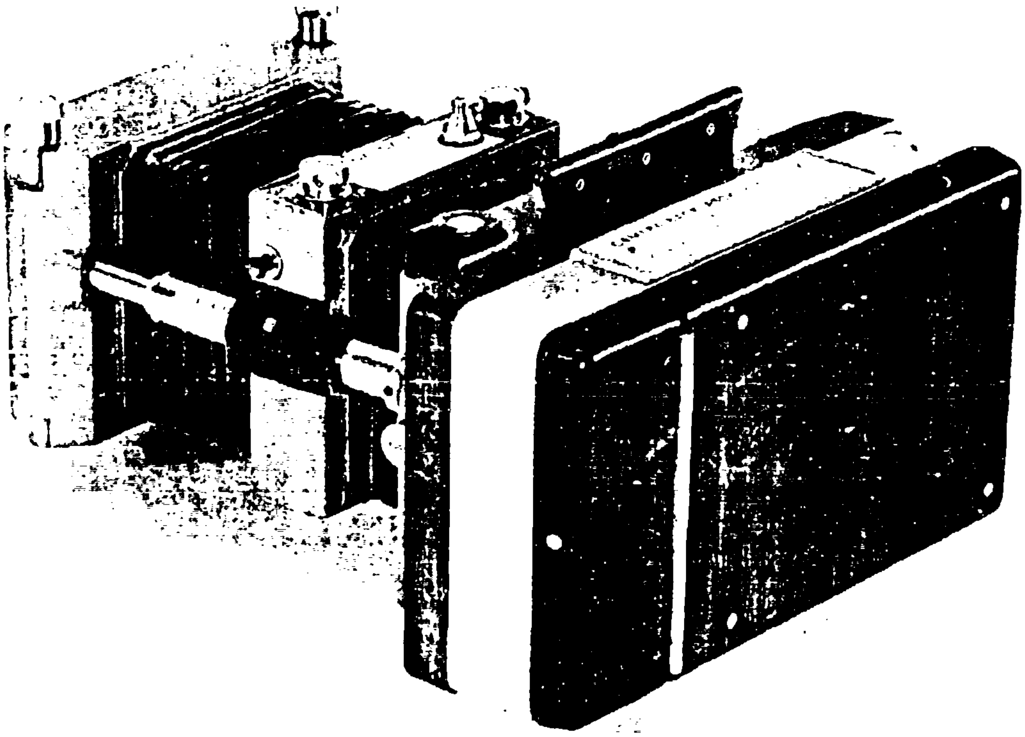


Fig. 1-1. Type C-30A Camera with Polaroid pack film back attached.

SECTION 1
CHARACTERISTICS

Change information, if any, affecting this section can be found at the rear of the manual.

General Description

The Tektronix Type C-30A Camera is specially designed for photographing oscilloscope displays. The optical system of the camera permits photographs to be made directly from the oscilloscope screen so the image is not reversed.

The camera provides many new convenience features, including slide-on type mountings with swing-away hinges so the camera can be swung out either to left or right for direct CRT display viewing.

The design of the Type C-30A Camera makes available a variety of object-to-image (MAG) ratios and allows the use of parfocal backs. The parfocal backs can be used with Polaroid[1] Land films or conventional films, in either sheet or roll film forms.

MAIN FRAME

Focusing

Focusing to compensate for slight differences between oscilloscopes (or for different MAG settings) is accomplished by means of a Focus knob on the left side. Once the Focus knob has been set, it may be locked in position with the Focus Lock knob, to prevent accidentally changing the Camera focus.

Mounting

The Type C-30A Camera is designed to mount directly to the Tektronix Type 422, 453, 453A, 454, 454A and 491. Refer to page 1-3 for additional adapters available for mounting the C-30A on other Tektronix oscilloscopes. (C-30A Option 1 requires removal of the corrector lens and use of a special adapter for mounting on these oscilloscopes, refer to the Option 1 insert for specific information.)

Optical System

Photographs are taken directly from the oscilloscope screen with no reversal. Object-to-image ratio may be varied from 1:0.7 to 1:1.5 in ten steps.

Viewing

The camera may be swung away from the CRT either to the left or right on its swing-away hinges to provide direct display viewing.

Size

See Fig. 1-2.

[1]Registered trademark of the Polaroid Corporation.

Weight

4 lbs., 13 oz. with Polaroid pack film back attached.

LENS

Lens (56 mm - f/1.9) and Shutter Settings

Both aperture (F stops) and shutter speed settings can be made from the top of the shutter box. X Synchronization contact connections are available on the bottom of the shutter box.

Shutter Speeds

(T), (B), and seven shutter speeds from 1 to 1/50 second.

f-Stops

1.9, 2.8, 4, 5.6, 8, 11 and 16.

MAG (Object-To-Image) Ratios

1 to 1.5, 1.4, 1.3, 1.2, 1.1, 1, 0.9, 0.85, 0.8 and 0.7.

CAMERA BACKS

Polaroid Land Pack Film Camera Back (122-0752-00)

Black-and-white or color film is available for the pack film back. Overall print size is 3 1/4 x 4 1/4 inches (maximum actual image size available is 7.3 x 9.5 cm). 100-Series Polaroid Land film packs should be used with this camera back.

Polaroid Land Roll Film Camera Back (122-0754-00)

Prints or transparencies in black and white or color prints may be obtained from a roll of film. Overall print size is 3 1/4 x 4 1/4 inches (maximum actual image size available is 7.3 x 9.5 cm). Only Polaroid Land roll film can be used with this back.

Graflok Camera Back (016-0487-00)

Any type of film holder which will attach to the 4 x 5 Graflok back can be used. The various attachments available will allow sheet or roll film of conventional types to be used. Maximum image size available is 3½ x 3¾ inches.